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ASSESSMENT OF WMATA'S AUTOMATIC FARE COLLECTION EQUIPMENT PERFORMANCE

J. Heisler
and
R. Stevens

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400 Totten Pond Road
Waltham MA 02154

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FINAL REPORT

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16. Abstract

This report summarizes the findings of an assessment of the Washington Metropolitan Area Transit Authority's (WMATA) automatic fare collection (AFC) equipment performance. The primary purpose of this study was to quantitatively evaluate, via standard statistical tests, the reliability and availability performance of WMATA's AFC systems and subsystems. The specific objectives were:

- To conduct a reliability and availability analysis of WMATA's fare-card vendors and their elements: ticket transports, coin acceptors and bill verifiers.
- To develop and apply a data collection and analysis plan to measure the effectiveness of equipment improvements to the ticket transport, coin acceptor and bill verifier.
- To estimate the impacts of AFC alternatives on system effectiveness.

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16. Abstract

The Washington Metropolitan Area Transit Authority (WMATA) has had an Automatic Fare Collection (AFC) system in operation since June 1977. The AFC system, comprised of entry/exit gates, farecard vendors, and addfare machines, initially encountered many operational set-backs due to unreliable equipment and an inadequate spare parts inventory. Equipment design problems were identified by WMATA in September 1977 and improvement programs directed toward improving AFC equipment reliability and availability continued through 1980. The first set of improvements occurred in December 1978 and January 1979 and were directed toward the farecard ticket transport. Modifications were made to the hinges, rollers, and printers of the AFC equipment. The second improvement program occurred in February 1980 and involved two separate programs. Retrofit A incorporated further changes to the ticket transport while Retrofit B included modification to the ticket transport, coin acceptor, and bill verifier. In light of the problems associated with WMATA's AFC system, this study was commissioned to quantitatively evaluate the reliability and availability of WMATA's AFC system and subsystems by way of standard statistical tests. The study was conducted in three separate phases, each with its own objective. The first phase focused on conducting a reliability and availability analysis of WMATA's farecard vendors and their elements (ticket transport, coin acceptor, and bill verifier) based on data collected in 1978 and 1979. The second phase was to develop and apply a data collection and analysis plan to measure the effectiveness of improvements (Retrofits A and B) to all AFC system equipment and their elements. The final phase utilized data generated from the first two phases to estimate the impacts of AFC alternatives on system effectiveness. This study presents the findings of each of the phases that were conducted.

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PREFACE

This study assesses the reliability and availability performance of the Washington Metropolitan Area Transit Authority's Automatic Fare Collection (AFC) equipment. The Transit Systems Branch of the Transportation Systems Center (U.S. DOT) supported this study as part of continuing research in the areas of automatic fare collection equipment performance and data base development. This report documents the findings of Input Output Computer Services, Inc. (IOCS) under contract number DOT-TSC-1669.

The research was performed and directed by J. Heisler. Charles Erdrich served as technical consultant for the study and reviewed study progress. S. Pozzi was the statistical consultant to the project; D. Mesnick and J. Morrissey were significant contributors to the study research. Joseph Koziol served as the contract technical monitor. The study also relied on the contributions of many who supplied performance data and information on WMATA's AFC system: Lloyd Johnson and Richard Klein at WMATA, and G. Persinger, L. Williams, and W. Stallworth from Automated Services, Inc.

METRIC CONVERSION FACTORS

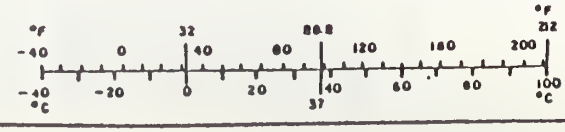
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SUMMARY

The Washington Metropolitan Area Transit Authority (WMATA) has had an Automatic Fare Collection (AFC) system in operation since June 1977. The AFC system, comprised of entry/exit gates, farecard vendors and add-fares, initially encountered many operational set-backs due to unreliable equipment and an inadequate spare parts inventory. Equipment design problems were identified by WMATA in September 1977 and improvement programs directed toward improving AFC equipment reliability and availability have continued through 1980. The first set of improvements occurred in December 1978 and January 1979 and were directed toward the farecard ticket transport. Modifications were made to the hinges, rollers and printers of AFC equipment. The second improvement program occurred in February 1980 and involved two separate programs. Retrofit A incorporated further changes to the ticket transport while Retrofit B included modification to the ticket transport, coin acceptor and bill verifier.

In light of the problems associated with WMATA's AFC system, this study was commissioned to quantitatively evaluate the reliability and availability of WMATA's AFC system and subsystems. The study was conducted in three separate phases, each with its own objective. The first phase of the study focused on conducting a reliability and availability analysis of WMATA's farecard vendors and their elements (ticket transport, coin acceptor and bill verifier) based on data collected in 1978 and 1979. The second phase of the study was to develop and apply a data collection and analysis plan to measure the effectiveness of improvements (Retrofits A and B) to all AFC system equipment and their elements. The final phase of the study utilized data generated from the first two phases to estimate the impacts of AFC alternatives on system effectiveness.

This report is divided into six sections. The first section describes the study purpose and objectives and defines the approach used to conduct the study. Section 2 presents various measures of reliability and availability which were used in analyzing WMATA's AFC equipment; a data collection plan is presented in Section 3. The analysis of WMATA's farecard vendor performance is contained in Section 4 and is followed by the analysis of the retrofit improvement program (Section 5). The AFC alternatives impact analysis is presented in Section 6. The following paragraphs give a brief summary of the results of each of these three phases of the study.

ANALYSIS OF THE RELIABILITY AND AVAILABILITY PERFORMANCE OF WMATA'S FARECARD VENDORS AND ELEMENTS

Data on transactions and failures obtained from approximately eight months of peak hour surveys at WMATA conducted in 1978-1979 were reduced and analyzed for farecard vendors and their elements. The results were combined to calculate reliability, availability, mean transactions per failure, and mean time between failures (MTBF). Statistical tests were employed to compare and rank farecard vendor and element performance.

The findings of the assessment of WMATA's farecard vendor performance may be summarized as follows:

1. Overall Farecard Vendor Performance by Mezzanine

   The mean number of transactions per failure at each mezzanine ranged from 97 to 192, with an overall mean of 120 transactions per failure. Two mezzanines, Silver Spring and Farragut West 17th St., had reliabilities significantly lower than the system average. No monthly trend in reliabilities was identifiable. Availabilities ranged from 79.80 percent to 90.70 percent, with a system mean of

84.10 percent. Monthly variation in availability within and among mezzanines followed no apparent trend. MTBF ranged from 1.60 to 3.30 hours, with a mean of 1.96 hours.

SUMMARY OF FARECARD VENDOR PERFORMANCE BY MEZZANINE, 1978-1979

MEZZANINE	MEAN TRANSACTIONS PER FAILURE	AVAILABILITY %	MTBF (HOURS)
DuPont Circle	192	90.68	3.30
Brookland	120	81.46	2.13
Silver Spring	99	83.21	1.86
Farragut West - 17th Street	97	79.77	1.58
Farragut West - 18th Street	129	84.50	1.94
Rosslyn	128	84.08	1.88
AVERAGE	120	84.08	1.96

2. Overall Element Performance

The coin acceptor element was significantly more reliable than both the ticket transport and the bill verifier. No significant difference was found between the reliabilities of the ticket transport and the bill verifier. Farecard jams comprised the greatest percentage (32 percent) of total failures. Bill jams accounted for 25 percent of the failures and coin jams, 18 percent. The remainder of the failures included hard failures (requiring a maintenance technician) - 14 percent, other soft failures - 10 percent and failure to verify a farecard - 1 percent.

SUMMARY OF FARECARD VENDOR ELEMENT PERFORMANCE, 1978-1979

	MEAN TRANSACTIONS PER FAILURE	PERCENT OF TOTAL FAILURES
1. Ticket Transport	376	32 - farecard jams
2. Coin Acceptor	844	18 - coin jams
3. Bill Verifier	358	25 - bill jams

3. Farecard Vendor-Specific: Overall and Element Performance

Low overall reliabilities in specific farecard vendors were traceable to one or more low element reliabilities. Of the forty vendors examined, seven had significantly lower reliabilities when compared to the system average. Eighteen vendors had availabilities significantly less than the system mean. Of these eighteen, five of the vendors also had the lowest reliabilities. The major cause of the low vendor availabilities was the lack of an adequate supply of spare parts and the lengthy out-of-service periods.

FARECARD VENDORS WITH RELIABILITIES SIGNIFICANTLY LESS (AT 95 PERCENT CONFIDENCE LEVEL) THAN OVERALL MEAN

MEZZANINE*	TOTAL FAILURES	FARECARD JAMS	COIN JAMS	BILL JAMS	HARD AND "OTHER" FAILURES
Brookland	31**		31		
Silver Spring	33		33		
	40	40	40		40
			30		
Farragut West 17th St.	32			32	
	33			33	
Rosslyn	39	39			
	41	41		41	

*DuPont Circle and Farragut West 18th St. did not have any farecard vendors with significantly low reliabilities.

**Vendor number.

FARECARD VENDOR AVAILABILITIES, 1978-1979

LOCATION	VENDOR	AVAILABILITY
DuPont Circle	30	99.25
	31	90.94
	32	81.28*
	38	95.14
	39	86.80
Brookland	30	95.27
	31	75.21*
	32	79.54*
	33	75.80*
Silver Spring	30	93.93
	31	74.24*
	32	88.24
	33	84.90
	34	95.42
	35	70.46*
	36	95.76
	40	59.04*
	41	81.67*
Farragut West - 17th Street	30	92.71
	31	88.06
	32	87.16
	33	73.71*
	34	71.22*
	35	65.74*
Farragut West - 18th Street	30	77.24*
	31	93.36
	32	74.78*
	33	74.86*
	34	89.41
	35	88.75
Rosslyn	30	80.79*
	31	81.99*
	32	87.42
	33	93.98
	34	92.44
	38	94.07
	39	53.88*
	40	88.11
	41	66.61*
	42	95.48

*Availability significantly (95 percent confidence level) below system mean.

ASSESSMENT OF THE RETROFIT EFFECTIVENESS ON AFC EQUIPMENT

Data were collected on the peak-hour reliability and availability performance of retrofit gates, farecard vendors, add-fare machines and their elements during February-April 1980. The data were then reduced and compared to the 1978-1979 survey data. Reliability and availability measures were statistically analyzed to determine the effectiveness of Retrofit A (improvements to the ticket transport) and Retrofit B (improvements to the ticket transport, bill verifier, and coin acceptor) in increasing AFC equipment performance.

The findings of the assessment of retrofit performance may be summarized as follows:

1. Overall Equipment Performance

   Retrofit A - Significant improvements in the reliabilities of gates occurred; farecard vendors and add-fares experienced no significant changes. The availabilities of gates and farecard vendors were significantly improved although only gates met 95 percent availability.

   Retrofit B - Significant improvements occurred in the reliabilities and availabilities of gates, farecard vendors and add-fares. All equipment achieved 95 percent operational availability. Retrofit B reliabilities showed significant improvements over Retrofit A and the availability of Retrofit B farecard vendors and add-fares was significantly better than that of Retrofit A.

COMPARISON OF MEAN TRANSACTIONS PER FAILURE FOR AFC EQUIPMENT: 1978-1979 SURVEY (Pre-Retrofit) AND 1980 SURVEY (Retrofits A and B) - TOTAL EQUIPMENT RELIABILITY

	MEAN TRANSACTIONS PER FAILURE[1]								
		RETROFIT A				RETROFIT B			
AFC EQUIPMENT	PRE RETROFIT	FEBRUARY	MARCH[2]	APRIL	TOTAL	FEBRUARY	MARCH	APRIL	TOTAL
Gates	502	525	3,496**	802**	712**	1,596**	4,865**	5,216**	2,220**
Farecard Vendors	120	115	109	197**	133	279**	189**	310**	265**
Add-fares	96	72	53	142	84	132*	313**	386**	174**

[1]Includes all hard and soft failures
[2]Farragut West, 17th St. only

*Significant improvement over 1978-1979 at 95 percent confidence level
**Significant improvement over 1978-1979 at 99 percent confidence level

COMPARISON OF AFC EQUIPMENT AVAILABILITIES: 1978-1979 SURVEY (Pre-Retrofit) AND 1980 SURVEY (Retrofits A and B) - TOTAL EQUIPMENT AVAILABILITY

	EQUIPMENT AVAILABILTY								
		RETROFIT A				RETROFIT B			
AFC EQUIPMENT	PRE RETROFIT	FEBRUARY	MARCH[1]	APRIL	TOTAL	FEBRUARY	MARCH	APRIL	TOTAL
Gates	92.71	95.30**	92.42	97.02**	95.54**	94.92**	98.87**	93.11	95.43**
Farecard Vendors	84.08	89.22**	92.07**	94.82**	91.61**	97.51**	96.32**	98.02**	97.61**
Add-fares	96.17	91.31	94.17	96.23	93.33	98.08**	99.49**	99.72**	98.67**

[1]Farragut West, 17th Street only

**Significant improvement over 1978-1979 at 99 percent confidence level

2. Overall Element Performance

Retrofit A - Gates and farecard vendors showed a significant increase in ticket transport reliability while add-fares showed a marked decrease. No significant improvements were found in the coin acceptor for farecard vendors; add-fares again showed a decrease in reliability. The bill verifier demonstrated an improvement in the farecard vendor and a significant improvement in the add-fares.

Retrofit B - Gates and farecard vendors demonstrated significant improvements in ticket transport reliability. Add-fares also had a marked increase in ticket transport reliability.

No significant improvements were found for the coin acceptor; add-fares experienced a decrease in coin acceptor reliability. The bill verifier demonstrated a significant improvement for farecard vendors and add-fares.

Retrofit B showed a significant increase in reliability over Retrofit A in the ticket transport for all equipment; there was no difference in Retrofit A and Retrofit B equipment performance for coin acceptors and bill verifiers.

3. Equipment Specific: Overall and Element Performance

Retrofit A

Rosslyn - All farecard vendors experienced improvements in ticket transport reliability; all other AFC equipment showed inconsistent performance. With the exception of a few machines, all AFC equipment met 95 percent availability.

COMPARISON OF MEAN TRANSACTIONS PER FARECARD JAM FOR AFC EQUIPMENT: 1978-1979 SURVEY (PRE-RETROFIT) AND 1980 SURVEY (RETROFITS A AND B) - TICKET TRANSPORT RELIABILITY

	MEAN TRANSACTIONS PER FARECARD JAM								
		RETROFIT A				RETROFIT B			
AFC EQUIPMENT	PRE RETROFIT	FEBRUARY	MARCH[1]	APRIL	TOTAL	FEBRUARY	MARCH	APRIL	TOTAL
Gates	858	1,381**	20,977/0**	1,034	1,477**	11,399**	8,109**	15,649**	11,274**
Farecard Vendors	376	477	510	885**	573**	6,148**	1,137**	4,965**	3,445**
Add-fares	552	143	79	243	154	833	939	772	872

[1]Farragut West, 17th St. only

**Significant improvement over 1978-1979 at 99 percent confidence level

COMPARISON OF MEAN NUMBER OF COINS INSERTED PER COIN JAM FOR FARECARD VENDORS AND ADD-FARES: 1978-1979 SURVEY (PRE-RETROFIT) AND 1980 SURVEY (RETROFITS A AND B) - COIN ACCEPTOR RELIABILITY

	MEAN NUMBER OF COINS INSERTED PER COIN JAM								
		RETROFIT A				RETROFIT B			
AFC EQUIPMENT	PRE RETROFIT	FEBRUARY	MARCH[1]	APRIL[1]	TOTAL	FEBRUARY	MARCH	APRIL	TOTAL
Farecard Vendors	844	1,062	734	2,893	1,058	1,125	956	871	1,027
Add-fares	2,115	412	690	924	510	1,082	563	824/0*	1,039

[1]Farragut West, 17th St. only

*Significant improvement on 1978-1979 at the 95 percent confidence level

COMPARISON OF MEAN NUMBER OF BILLS INSERTED PER BILL JAM FOR FARECARD VENDORS AND ADD-FARES: 1978-1979 SURVEY (PRE-RETROFIT) AND 1980 SURVEY (RETROFITS A AND B) - BILL VERIFIER RELIABILITY

	MEAN NUMBER OF BILLS INSERTED PER BILL JAM								
		RETROFIT A				RETROFIT B			
AFC EQUIPMENT	PRE RETROFIT	FEBRUARY	MARCH[1]	APRIL[1]	TOTAL	FEBRUARY	MARCH	APRIL	TOTAL
Farecard Vendors	358	444	553	299	459	622**	305	971**	572**
Add-fares	40	616**	130/0**	203**	474**	311**	281/0**	432/0**	454**

[1]Farragut West, 17th St. only

**Significant improvement over 1978-1979 at 99 percent confidence level

Farragut West, 17th Street - Gates had significant improvements in ticket transport reliabilities; farecard vendors showed minor improvements. An availability of 95 percent was not met by a large portion of the equipment and farecard vendors were particularly inconsistent performers.

Retrofit B

Farragut West, 18th Street - All gates and farecard vendors had an increase in ticket transport reliabilities, and all AFC equipment experienced an increase in total reliability. There was a decrease in the reliability of the coin acceptors; bill verifiers showed marked improvements. With the exception of one gate and one farecard vendor, all AFC equipment met 95 percent availability.

4. Analysis of peak and off-peak performance resulted in a wide disparity among data from which no conclusions could be made.

IMPACT OF FARE COLLECTION ALTERNATIVES

Reliability measures for AFC equipment were combined with passenger flow distributions to provide an estimate of system reliability measured in terms of the probability of a successful transaction. The average down time (ADT) per failure system-wide (measure of maintainability) was estimated by weighting the ADT of hard and soft failures by the ratio of soft to hard failures. System reliability and maintainability were then compared at Farragut West, 18^{th} St. for the following fare collection alternatives.

1. Improved ticket transport, coin acceptor and bill validator (Retrofit B);

2. $1 and $5 fast vendors;

3. One- or two-ride fast vendors; and

4. Current AFC system operating under optimal performance (10,000 transactions per failure and 95 percent availability).

The results of the comparison of alternatives showed that the highest system reliability and lowest maintainability could obviously be achieved at optimal performance. The $1 and $5 fast vendors had the second best system reliability, followed closely by one- and two-ride fast vendors. A more extensive analysis of the costs and benefits of the various alternatives is required to make any conclusive recommendations.

COMPARISON OF AFC ALTERNATIVES: SYSTEM RELIABILITY AND ADT PER FAILURE, FARRAGUT WEST, 18TH ST.

ALTERNATIVE	SYSTEM RELIABILITY-FAILURES PER 10,000 TRANSACTIONS	ADT[1] PER FAILURE
1978-1979 System	26	6.73
Retrofit B	12	12.53
$1 and $5 Fast Vendors	10	12.85
One- and Two-Ride Fast Vendors	11	12.49
Optimum Performance of AFC Equipment	1[2]	4.25

[1]Peak-Hour Minutes

[2]Defined by The Performance Standard of 10,000 Transactions per Failure

1. INTRODUCTION

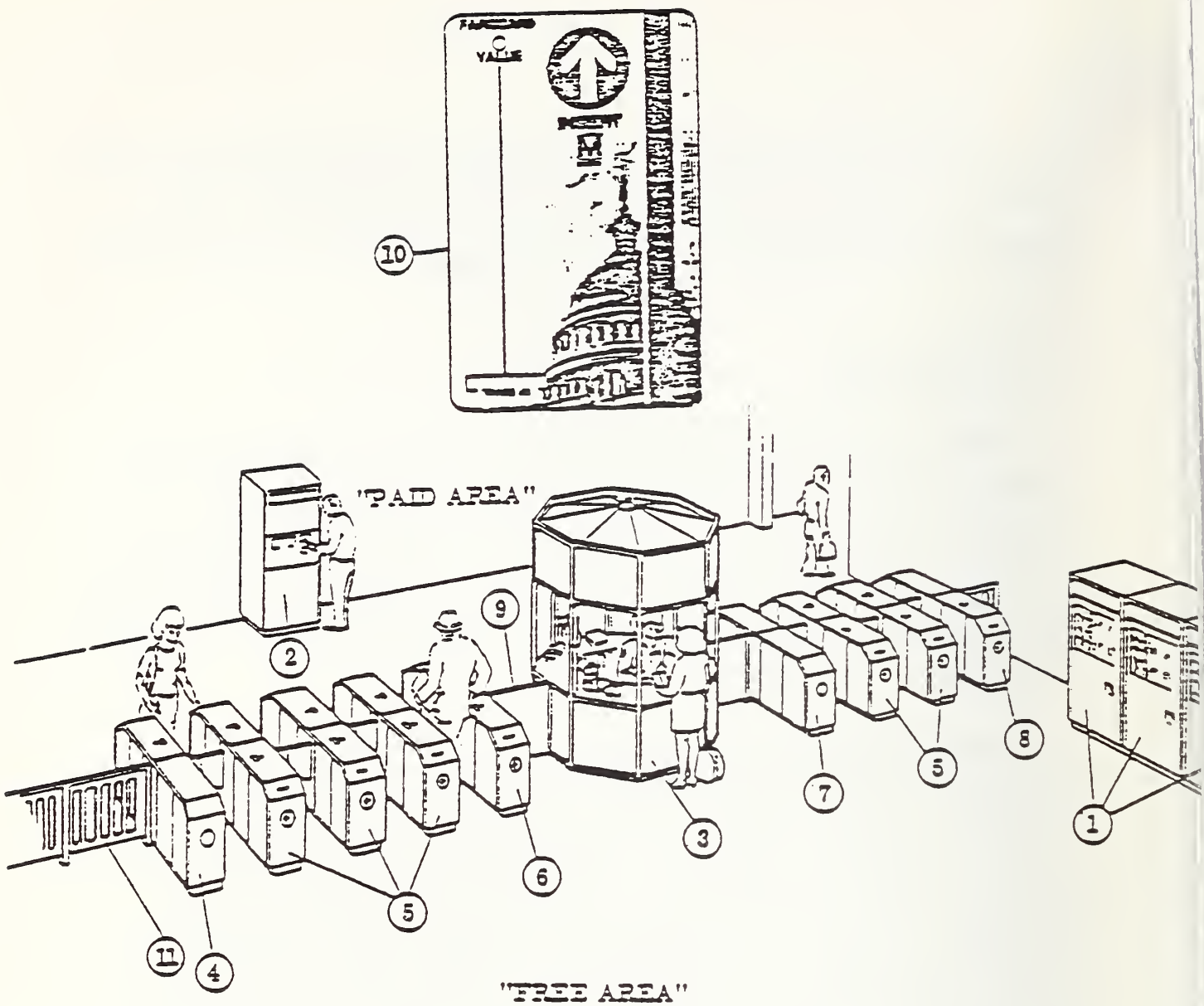
This report summarizes the findings of an assessment of the reliability and availability performance of automatic fare collection (AFC) equipment at selected Washington Metropolitan Area Transit Authority (WMATA) mezzanines.

1.1 BACKGROUND

WMATA's AFC system is a refined version of the Bay Area Rapid Transit (BART) second-generation AFC system. The equipment was designed by Cubic Western Data (CWD). The AFC system is composed of farecard vendors, add-fare machines, entry and exit gates, and a Data Acquisition and Display System (DADS) which monitors and controls the AFC equipment at each mezzanine. (See Figure 1-1.)

The farecard vendors furnish farecards of any chosen value from $0.45 to $20.00 for cash or cash plus the trade-in value of a used farecard. Vendors at WMATA accept $1 and $5 bills, and nickles, dimes and quarters. The vendors also return up to $4.95 in change. The entry and exit gates separate the paid from the free area in a mezzanine, and they read, encode and verify information on the farecards. Exit gates also print the value remaining on a farecard so patrons have a record of the remaining value. Add-fare machines accept farecards, calculate the additional fare required to exit the system, and visually display the required amount to the patron. Similar to farecard vendors, they accept bills and coins. In addition, all WMATA add-fare machines will change $1 and $5 bills into quarters without an associated farecard.

A DADS system is located in each mezzanine and is electrically connected to each machine. The system accepts



KEY NO.	NAME	KEY NO.	NAME
1	Farecard Vendor	6	End A Gate
2	Addfare Machine	7	End B Gate
3	Station Attendant Kiosk w/DADS	8	Entry Gate
		9	Service Gate
4	Exit Gate	10	WMATA Farecard
5	Reversible Gate	11	Railing

FIGURE 1-1. WMATA MEZZANINE WITH AFC EQUIPMENT

signals from equipment registers and malfunction/intrusion status sensors. Malfunctions are indicated on a display panel located in the kiosk which lights up and identifies both the machine number and the type of malfunction. The DADS system also provides accounting data for each machine in the form of a register printout. These printouts are available at any time on a machine-specific basis. DADS generates and transmits time signals to all gates to change fare calculations during off-peak hours. All AFC machines can be remotely put in or out of service by DADS, and entry and exit modes can be changed on gates.

WMATA's AFC system has been in operation since June 1977. Initially the AFC system encountered many set-backs including inadequate equipment quantities at high volume stations and unreliable equipment. Maintenance and operational inefficiencies such as coordinating maintenance tasks and maintaining an adequate parts inventory also contributed to early AFC problems. By September of 1977, CWD and WMATA had identified three general areas of equipment design problems: money handling equipment, farecard transports, and software. CWD undertook an AFC improvement program to increase the reliability and maintainability of the AFC equipment. WMATA reviewed AFC equipment performance and identified design objectives having the highest potential for improving equipment reliability and availability. Six objectives were given high priority:

1. Decrease farecard jams in all transports.

2. Increase bill validator performance and reliability.

3. Increase coin acceptor reliability.

4. Decrease the number of coin jams in the coin chute.

5. Improve faregate register reliability and accuracy.

6. Eliminate rejection of valid currency caused by timing between bill validator and bill escrow.

To monitor the improvement program, WMATA began a series of monthly peak-hour surveys. These surveys provided data on selected AFC equipment performance and usage from October 1978 to September 1979.

1.2 STUDY PURPOSE AND OBJECTIVES

In light of the problems associated with WMATA's AFC system performance, the purpose of this study was to quantitatively evaluate via standard statistical tests the reliability and availability performance of WMATA's AFC system and subsystems. The specific objectives of the study were:

1. Conduct a reliability and availability analysis of WMATA's farecard vendors and their elements;

2. Develop and apply a data collection and analysis plan to measure the effectiveness of improvements (retrofits) to AFC system elements; and

3. Estimate the impacts of AFC alternatives on system effectiveness.

1.3 STUDY APPROACH

To accomplish the study objectives, six steps were taken. First, existing reliability and availability studies of AFC equipment and literature on reliability engineering and quality control were surveyed. This survey helped establish and define

the reliability and availability measures to be utilized at WMATA. Second, raw data from WMATA's monthly surveys were obtained and failure and transaction data were reduced. Third, failure, transaction and operating time data were combined to calculate measures of reliability and availability. Fourth, statistical tests were utilized to compare farecard vendor and element performance, and to rank element reliabilities. The fifth step consisted of designing a data collection and analysis plan to measure retrofit performance, and reducing and comparing the post retrofit data to earlier WMATA survey results. Finally, the results of the reliability and availability analysis were utilized as inputs to estimate the impacts of automatic fare collection alternatives on system effectiveness.

2. RELIABILITY AND AVAILABILITY AS MEASURES OF SYSTEM PERFORMANCE

The performance of a specified function is the output of any given system. System effectiveness is a term used to describe the overall capability of a system to accomplish its intended function. Effectiveness encompasses system design, use, and maintenance as well as administrative and policy decisions that support system operation. Reliability and availability are two quantitative measures of performance which refer to the operational readiness of a system. Maintainability is another measure of the operational readiness of a system.

Literature and existing studies on reliability and availability provide confliciting interpretations of this terminology. As a result, many different quantitative measures or formulas for calculating reliability and availability exist. To ensure precise communication of the study results, this chapter will discuss and define reliability, availability and maintainability as applied to the analysis of WMATA's AFC system performance.

2.1 RELIABILITY AND AVAILABILITY MEASURES OF WMATA'S AFC EQUIPMENT AND ELEMENTS

For the purposes of this study, reliability is defined as the probability that AFC equipment or their elements will successfully accomplish their functional tasks. For each type of AFC equipment, gates, farecard vendors, and add-fare machines, the functional task referred to is a successful transaction. A transaction for entry and exit gates occurs when a patron successfully uses a farecard to enter or exit the system. For farecard vendors, a transaction occurs when a

patron successfully purchases or adds additional value to a farecard. For add-fare machines, a transaction involves a successful purchase of additional value for a farecard.

A failure occurs when a machine or an element does not accomplish its functional task. By summing total transactions and total machine failures, reliability can be calculated for each type of AFC equipment:

$$R = \frac{\text{Total transactions - total failures}}{\text{Total transactions}}$$

Transactions may be measured on a system, mezzanine, machine or element level. When reliability is expressed as a probability, it facilitates subsequent quantitative analysis. However, reliability measures may be converted to mean transactions per failure by utilizing the following formula:

$$\text{Mean Transactions per Failure} = \frac{1}{1 - R}$$

Transactions for the elements of AFC equipment are measured in terms of the actual functional task of each element. A transaction for an element occurs each time an element is utilized. This allows for a determination of element reliability based on actual element usage as opposed to overall equipment usage. The elements examined in this study are:

1. Ticket transports - for gates, farecard vendors, and add-fares. The ticket transports are utilized in every successful transaction, so the total number of transactions per AFC machine is used to measure the number of times a ticket transport was utilized successfully.

2. Coin acceptors - for farecard vendors and add-fares. The coin acceptor is often utilized more than once in a successful transaction, (i.e., a patron inserts two quarters for one fare).* The total number of coins inserted into a machine measures the number of times the coin acceptor was utilized successfully.

3. Bill Validator - for farecard vendors and add-fares. To measure the number of times a bill validator was successfully utilized, the total number of $1 and $5 bills accepted by a machine was summed.

It is particularly useful to measure coin and bill reliabilities based on actual usage since these elements are purchased commercially, and performance specifications apply to the particular element as opposed to the AFC machine. Reliabilities may be calculated on an element level utilizing element transactions and failures. For WMATA this is possible because DADS records the number of bills and amount of change input to any farecard vendor or add-fare machine. An estimate of the number of coins input to any machine can be obtained by applying a coinage distribution to the amount. Reliabilities for each of the elements are calculated using the following formulas:

1. Ticket transport

$$R = \frac{\text{Total transactions - total farecard jams}}{\text{Total transactions}}$$

*For two sample survey periods at WMATA, the average number of coins per transaction was observed for farecard vendors only:

Farragut West, 17th St., Off-Peak: 1045-1245 - 2/26/80
Average Number of Coins per Transaction: 2.66

Farragut West, 18th St., Peak: 1700-1830 - 2/26/80
Average Number of Coins per Transaction: 2.56

2. Coin acceptor

$$R = \frac{\text{Total coins accepted* - total coin jams}}{\text{Total coins accepted}}$$

*where the coin distribution is as follows:

quarters	= 82 percent
dimes	= 12 percent
nickels	= 5 percent
half-dollars	= 1 percent

3. Bill validator

$$R = \frac{\text{Total bills accepted - total bill jams}}{\text{Total bills accepted}}$$

Reliability measured in this manner assumes a situation dependent on use as opposed to time.**

Availability for the purpose of this study is defined as the probability that AFC equipment will be operating satisfactorily at any point in time. The total time considered includes operating time, active repair time, and logistic time (response time). Total operating time (combined survey period time) and repair and logistic time (combined duration of failures) are utilized to calculate availability.

$$A = \frac{\text{Total operating time - total down time}}{\text{Total operating time}}$$

*For two sample survey periods at WMATA, the average number of coins per transaction was observed for farecard vendors only:

Farragut West, 17th St., Off-Peak: 1045-1245 - 2/26/80
Average Number of Coins per Transaction: 2.66

Farragut West, 18th St., Peak: 1700-1830 - 2/26/80
Average Number of Coins per Transaction: 2.56

**This assumption was tested by establishing a positive correlation between the number of transactions and number of failures occurring at each type of equipment. A linear regression was performed, and a T-test yielded 97 percent confidence of a positive correlation.

Down time is the amount of time an AFC machine was out of service due to all or some type of failures. Availability may be measured on a system, mezzanine, or machine level.

Mean time between failures (MTBF) is a performance measure (also used as a measure of reliability) which combines the number of failures with the operating time to estimate the relative time period between expected failures.

$$\text{MTBF} = \frac{\text{Total operating time}}{\text{Total failures}}$$

MTBF can be used as a measure of maintainability when it refers to the distribution of active repair times as opposed to failures. When MTBF is calculated based on the total number of failures, it provides useful information for maintenance personnel scheduling. However, it does not directly take into account the rate of machine usage, an important variable in AFC equipment performance due to its non-uniform utilization over time. MTBF may be calculated at a system, mezzanine, machine and element level.

Reliability is the probability that a failure will occur while availability is the probability that a machine will not be out of service due to a failure. MTBF provides an estimate of the relative time period between expected failures.

2.2 EXISTING RELIABILITY AND AVAILABILITY STUDIES OF WMATA'S AFC EQUIPMENT

Three studies have examined the performance of WMATA's AFC equipment. Each focused on particular equipment and/or measures of reliability and availability. The first study was performed by CWD as part of its contractual agreement with WMATA. A detailed test plan was submitted in January of 1977 to cover a 12-month survey period, August 1977 to July 1978.

CWD's survey included 96 in-service AFC units apportioned among all of the AFC equipment types. Two measures of reliability and maintainability were employed to demonstrate compliance with AFC requirements: MTBF and mean time to repair (MTTR). The latter measure was calculated as follows:

$$\text{MTTR} = \frac{\text{Total primary level* repair time}}{\text{Total failures}}$$

The performance criteria established by CWD for its three types of AFC equipment are listed in Table 2-1.

TABLE 2-1. CWD PERFORMANCE CRITERIA FOR WMATA'S AFC EQUIPMENT

EQUIPMENT TYPE	MTBF HOURS	MTBF DAYS	MTTR HOURS
Gates	720	36	0.5
Farecard vendors	920	46	0.5
Add-fares	744	37	0.5

This set of criteria only includes hard failures which require repair by a maintenance person. All jams (fare card, coin, or bill) that may be cleared by a station attendant (soft failures) are excluded.

*Primary level repair time refers to repairs made at the "line" or mezzanine. It includes fault isolation, replacement of the defective unit, and retest; it does not include scheduled maintenance, coin, bill or card jam clearance or patron-induced failures. Also not included in primary level repair time are response time from the time of failure to the arrival at the mezzanine, delay time for procuring spare parts, and other time interruptions of the repair task.

The CWD survey and analysis measured only failures which required technical repair action. It assumed uniform usage of AFC equipment by utilizing only MTBF as a measure of reliability. In addition, MTTR measured active repair time only, not total out-of-service time for each failure, and MTTR was based on a 24-hour operating day.

The second study consisted of a series of monthly AFC equipment performance studies conducted by WMATA. The WMATA surveys covered the time period October 1978 to September 1979. For two days a month, both a.m. and p.m. peak hours were surveyed. WMATA analyzed the data by mezzanine and equipment type (gates, farecard vendors and add-fares). Failures were itemized by type of failure: total jams, total farecard jams, total bill jams, total coin jams, and total money handling jams. Overall availability was also calculated by AFC equipment type.

The third study of WMATA's AFC equipment was part of a Fare Collection Overview Report by the Jet Propulsion Laboratory (JPL). JPL utilized WMATA's survey information to calculate total transactions per failure by failure type, (hard, soft, bill, coin and farecard jam) and by equipment type.

MTBF was also calculated on the assumption that peak hour transactions per unit time were uniform. Reliability was then derived based on an exponential distribution of failures.

$$R = \exp(-t/\theta)$$

t = 24 hours

θ = MTBF

The assumption that peak hour transactions per unit time are uniform is fairly accurate for vendors,* but questionable for entry and exit gates as some are reversible and the attendant can change the entry or exit mode.** However, this method of calculating reliability is one way to portray the probability of no failures occurring within a peak period; extrapolating to a 24-hour period could be misleading since usage is not uniform throughout the day. This technique also assumes a specified rate of usage since operating time and failures (MTBF) are included. Reliability expressed in this form applies only to a specific usage situation.

The three previous studies measured slightly different aspects of WMATA's AFC equipment reliability, availability, and maintainability. This study attempts to standardize these measurements to analyze AFC equipment and element reliabilities in detail and determine the effectiveness of modifications on equipment reliabilities.

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*Average transactions per peak hour were calculated on a machine-specific basis, and two statistical tests were utilized to test for machine differences. The Chi square test indicated discrepancies from the assumption of a uniform distribution. The Kolmogorov-Smirnov indicates a uniformity in machine usage.

**Average transactions per peak hour for individual entry and exit gates varied substantially.

3. DATA COLLECTION AND REDUCTION

To calculate measures of reliability and availability for WMATA's AFC equipment, two primary data sources were utilized: data collected at WMATA on AFC equipment failures and their duration, and DADS tapes containing transaction data for the survey periods. Three surveys provided failure data. Two surveys were conducted by WMATA and one was conducted jointly by IOCS and Automated Services Incorporated (ASI).

3.1 WMATA'S 1978-1979 SURVEYS

The 1978-1979 surveys provided approximately eight months of peak hour data for six mezzanines, four of which were designated as baseline or primary survey mezzanines. Raw data sheets and copies of the DADS printouts were obtained from WMATA. Table 3-1 summarizes the failure data available for 1978-1979, and Table 3-2 summarizes the available DADS tapes. Some of the DADS tapes were unavailable for certain peak periods or for certain machines due to malfunctions in the DADS, illegible printouts, or incorrectly coded data. No attempt was made to estimate missing transactions since this would have involved estimating bill and coin transactions as well.

Transaction and failure data were reduced for all farecard vendors, and the results were combined to estimate reliability, availability, and transactions per failure. Failure data was manually recorded by vendor, failure type and duration for each mezzanine. Figure 3-1 shows a sample survey sheet. Transaction data were obtained for each vendor by calculating the differences between DADS printouts for the start and finish of each survey period. Figure 3-2 shows sample DADS printouts and explanation of the coding. Failures were classified as shown in Table 3-3, and applied to the appropriate element. The data

TABLE 3-1. SUMMARY OF RAW SURVEY DATA, 1978-1979

MEZZANINE	NO.	1978			1979						
		OCT.	NOV.	DEC.	JAN.	FEB.	MARCH	APRIL	MAY	JUNE	AUG.
DuPont Circle (S)	05		X	X	X	X	X	X	X	X	X
Judiciary Sq. (E)	23						X				
Brookland	27	X	X	X	X	X	X	X	X	X	X
Silver Spring (S)	30*	X	X	X	X	X	X	X	X	X	X
Farragut West-E (17^{th})	38*	X	X	X	X	X	X	X	X	X	Sept.
Farragut West-W (18^{th})	39*	X	X	X	X	X	X	X	X	X	X
Rosslyn	41*	X	X	X	X	X	X	X	X	X	X
Pentagon	43								X		
National Airport	46								X		
Metro Center (S)	52					X					
New Carrollton	68			X							

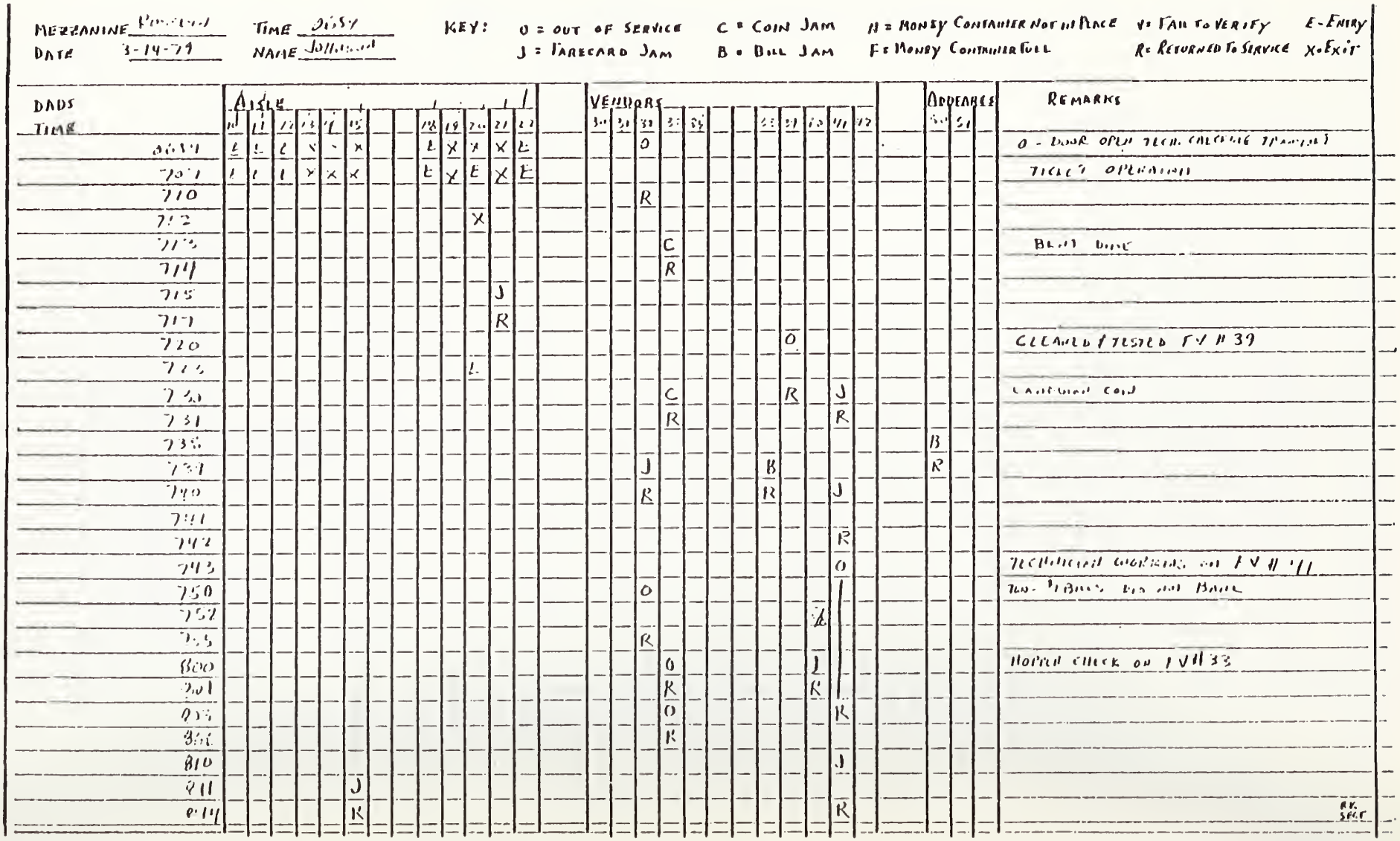
*baseline

TABLE 3-2. SUMMARY OF DADS DATA, 1978-1979

MEZZANINE	NO.	1978						1979															
		OCTOBER				NOVEMBER				DECEMBER		JANUARY				FEBRUARY		MARCH		APRIL		MAY		JUNE		AUGUST	
		17		18		14		15		12	13	16		17		27	28	13	14	24	25	15	16	19	20	28	29
		A	P	A	P	A	P	A	P	A P	A P	A	P	A	P	A P	A P	A P	A P	A P	A P	A P	A P	A P	A P	A P	A P
DuPont Circle (S)	05					X	X	X	X	X X	X X	X	X	X	X	X X	X X	X X	X X	X X	X X	X X	X X			X X	X O
Judiciary Sq. (E)	23															X X	X X										
Brookland	27					X	X	X	X			X	X	X	X	X X	X X	X X	X X	O X	X X	X X	X X	X X	X X	X X	X X
Silver Spring (S)	30*	X	X	X	X					X X	X X	X	X	X	X	X X	X X	X X	X X	X X	X O	X X	X X	X X	X X		
Farragut West-E (17th)	38*	O	O	O	O	X	X	X	X	X X	X X	O	O	X	X	X O	O X	X X	O O	X X	X O	X O	X X	X X	X X		
Farragut West-W (18th)	39*	X	X	X	X					O X	X X	X	X	X	O	X X	X X	O X	* *	X X	X O	X X	X X	X X	X X		
Rosslyn	41*	X	X	X	X					X X	X X	X	X	X	X	O O	X X	X X	X X	X X	X X	X X	X X	X X	X X	X X	X X
Pentagon	43																					X X	X O				
National Airport	46																	O X	O X								
Metro Center (S)	52																	X X	X X								
New Carrollton	68											X	X	X	X												

Key: Blank or O = Not Available
X = Available
* = Available but Illegible
A = AM
P = PM

FIGURE 3-1. SAMPLE SURVEY FORM



1. Gate (Reversible Exit and Entry Modes) #11

0000002790	Patrons In
0001703095	Fare Extracted
0000000475	'B'
0000000308	'A'
0000000593	Zero Value Captured
0000004026	Patrons Out
0000004111	Mezzanine and Machine Number
0790161826	Year, Julian Date, Time

2. Farecard Vendor #31

0000265325	$ Change
0001035200	$ Old Farecards
0000011200	$ Bonus Paid
0008910600	$ Amount Issued
0000214115	$ Coins Accepted
0000000755	Farecards Not Verified
0000039097	Farecards Accepted
0000092519	Number of Successful Transactions
0000007366	$5 Bills Accepted
0000067672	$1 Bills Accepted
0000004131	Mezzanine and Machine Number
0790161827	Year, Julian ate, Time

3. Add-Fare #50

0000052325	$ Change
0000381720	$ Coins Accepted
0000685205	$ Amount Issued
0000003883	$5 Bills Accepted
0000007269	$1 Bills Accepted
0000006724	Number of Successful Transactions
0000004150	Mezzanine and Machine Number
0790161828	Year, Julian Date, Time

FIGURE 3-2. DADS PRINT-OUTS ATC FOR AFC EQUIPMENT

TABLE 3-3. CLASSIFICATION OF AFC EQUIPMENT FAILURES

J = Farecard Jam.

This may occur in all types of equipment when the farecard is processed through the transport and encoded, read and verified.

C = Coin Jam.

This occurs in the farecard vendor and add-fare machines, usually due to a bent or foreign coin.

B = Bill Jam.

This occurs in the farecard vendor and add-fare machines, usually due to torn or crumpled bills.

V = Failure to Verify.

This occurs in the farecard vendors, gates, and add-fares when the machine cannot verify the value or other information coded on the farecard.

O = Out-of-Service

This classification covers many types of soft failures, including those that occur for no identifiable reason. This is used for all other soft failures.

H = Hard Failures

This group includes machines that are out of service because they are awaiting parts. It applies when a machine is worked on by a maintenance person, or when a call for maintenance person occurs. It also applies to situations where a constant coin, ticket or bill jam occurs and the machine is put out-of-service by an attendant.

were grouped by vendor and mezzanine and combined to obtain monthly averages.

Generally, data were of good quality and a large sample was available for each mezzanine although peak period data were missing for some equipment. Some of the problems encountered in data reduction included: illegibility of survey sheets, non-uniform classification of failures, inadequate supplemental information to document all hard and "other" out-of-service failures, and missing DADS tapes or DADS tapes with illegible information. Future analyses of AFC equipment will require the elimination of these problems to ensure complete and consistent data documentation.

3.2 1980 RETROFIT SURVEY

The 1980 survey of WMATA's AFC equipment performance was directed at measuring the effectiveness of certain improvements in AFC elements. Since the summer of 1979, WMATA has been conducting a special program to improve the performance of:

1. Transport mechanisms
2. Printers
3. Bill validators
4. Coin acceptors
5. Farecards

WMATA, in conjunction with CWD, undertook two improvement projects designated as Retrofit A and Retrofit B:

Retrofit A - This retrofit involved changes to various components of the ticket transport to decrease the incidence of farecard jams. Three WMATA mezzanines received Retrofit A in January 1980:

- Farragut West (17th Street)
- Rosslyn
- Dupont Circle (South)

Retrofit B - This retrofit involved changes to the bill verifier, coin acceptor and ticket transport. These retrofits were designed to increase element reliability and reduce maintenance requirements. One WMATA mezzanine received Retrofit B in February 1980:

- Farragut West (18th Street)

Two mezzanines receiving Retrofit A, Farragut West 17th Street and Rosslyn, and the one receiving Retrofit B, Farragut West 18th Street, were selected for survey purposes. Figure 3-3 summarizes the data collection schedule.

The retrofit survey was structured to remedy a few of the data collection problems previously encountered. All DADS information was manually recorded on separate sheets as back-up to the DADS tapes. In addition, data collectors kept an activities log and recorded descriptive information on each failure and indicated who was responsible (maintenance technician or attendant) for clearing the failure. Appendix 1 contains sample survey forms and procedures. Post-retrofit data were reduced and reliability and availability measures were compared to 1978-1979 data for farecard vendors, and to a sample of data (January, February 1979) for gates and add-fares.

LOCATION	FEBRUARY 1980						MARCH 1980								APRIL 1980		
	THUR 21	MON 25	TUES 26	WED 27	THUR 28	FRI 29	MON 3	TUES 4	WED 5	THUR 6	FRI 7	WED 12	WED 19	WED 26	TUES 15	WED 16	THUR 17
WMATA	Training session 0900-1600																
Farragut West 17th St. (A)		0700-0900 1600-1830	1100-1400			0700-0900 1600-1830	0700-0900 1600-1830	1100-1400				1600-1830	0700-0900	1600-1830	0700-0900 1600-1800	1600-1800	0700-0900
Rosslyn (A)					0700-0900 1600-1830					0700-0900 1600-1830					0700-0900- 1600-1800	0800-1000- 1600-1800	
Farragut West 18th St. (B)			0700-0900 1600-1830	0700-0900 1100-1400 1600-1830				0700-0900 1600-1830	0700-0900 1100-1400 1600-1830		0700-0900 1600-1830	0700-0900	1600-1830	0700-0900	0700-0900 1600-1800	1600-1800	0700-0900

FIGURE 3-3. 1980 RETROFIT SURVEY DATA COLLECTION SCHEDULE

4. ANALYSIS OF WMATA'S FARECARD VENDOR RELIABILITY AND AVAILABILITY - 1978-1979

The survey data were reduced and reliability and availability measures were analyzed at three levels of detail:

1. Overall farecard vendor performance by mezzanine;

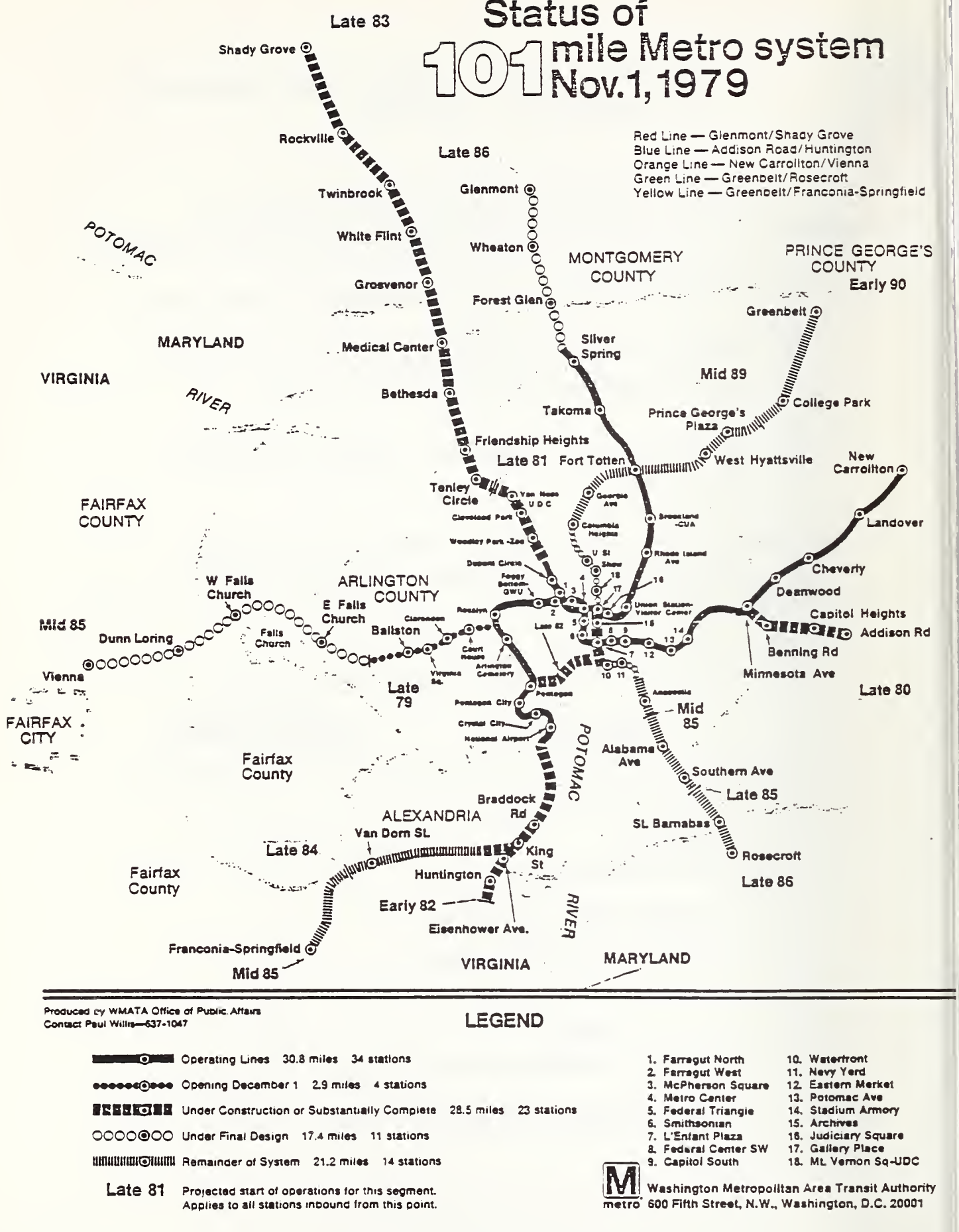
2. Overall element performance for ticket transports, coin acceptors and bill verifiers; and

3. Farecard vendor-specific: overall and element performance.

Six mezzanines were examined for a total of 40 farecard vendors. The mezzanines and number of farecard vendors at each are listed below.

MEZZANINE	NUMBER OF FARECARD VENDORS
1. DuPont Circle (S)	5
2. Brookland	4
3. Silver Spring (S)	9
4. Farragut West 17th Street	6
5. Farragut West 18th Street	6
6. Rosslyn	10
TOTAL	40

The map of WMATA's system in Figure 4-1 shows the location of these mezzanines.



Produced by WMATA Office of Public Affairs
Contact Paul Willis—637-1047

LEGEND

- Operating Lines 30.8 miles 34 stations
- Opening December 1 2.9 miles 4 stations
- Under Construction or Substantially Complete 28.5 miles 23 stations
- Under Final Design 17.4 miles 11 stations
- Remainder of System 21.2 miles 14 stations

Late 81 — Projected start of operations for this segment. Applies to all stations inbound from this point.

1. Farragut North
2. Farragut West
3. McPherson Square
4. Metro Center
5. Federal Triangle
6. Smithsonian
7. L'Enfant Plaza
8. Federal Center SW
9. Capitol South
10. Waterfront
11. Navy Yard
12. Eastern Market
13. Potomac Ave
14. Stadium Armory
15. Archives
16. Judiciary Square
17. Gallery Place
18. Mt. Vernon Sq-UDC

Washington Metropolitan Area Transit Authority
600 Fifth Street, N.W., Washington, D.C. 20001

FIGURE 4-1. WMATA SYSTEM MAP

4.1 OVERALL FARECARD VENDOR PERFORMANCE BY MEZZANINE

Overall farecard vendor reliabilities were calculated by summing the total transactions and total failures (hard and soft) for each mezzanine. The mean number of transactions per failure and reliabilities are shown in Table 4-1 for all mezzanines together and individually. Ninety-five percent confidence intervals are shown in parentheses in Table 4-1. Figure 4-2 presents transactions per failure in bar-chart form.

TABLE 4-1. RELIABILITY AND MEAN TRANSACTIONS PER FAILURE FOR FARECARD VENDORS, 1978-1979, MEZZANINE AND TOTAL

MEZZANINE	RELIABILITY	MEAN TRANSACTIONS PER FAILURE*
DuPont Circle	0.9948 (0.9938 - 0.9958)	192
Brookland	0.9917 (0.9902 - 0.9932)	120
Silver Spring	0.9899 (0.9888 - 0.9910)	99
Farragut West - 17th Street	0.9897 (0.9883 - 0.9911)	97
Farragut West - 18th Street	0.9923 (0.9911 - 0.9935)	129
Rosslyn	0.9922 (0.9914 - 0.9930)	128
TOTAL	0.9917 (0.9912 - 0.9922)	120

*Includes all hard and soft failures.

( ) = 95 percent confidence interval.

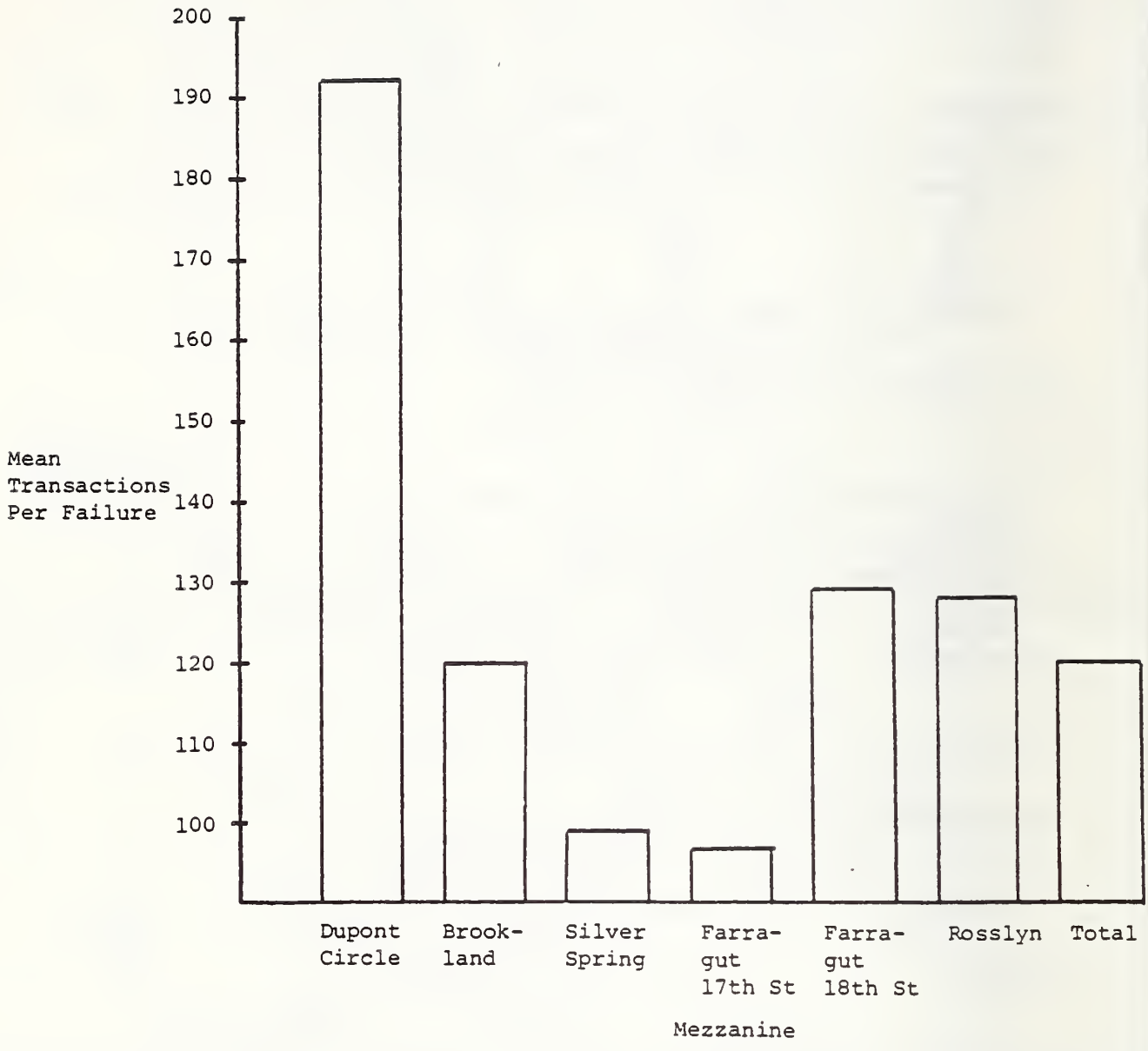


FIGURE 4-2. MEAN TRANSACTIONS PER FAILURE FOR FARECARD VENDORS, 1978-1979, MEZZANINE AND TOTAL

Due to random variation, farecard vendors were expected to have different reliabilities. To determine whether the differences in reliabilities were due to chance or due to actual variations in vendor performance, a Chi-square test for equality of proportions was utilized. (See Appendix 2 for a discussion of this statistic.) At a 95 percent confidence level, the Chi-square test indicated that differences existed in mezzanine reliabilities for farecard vendors.

One of the difficulties of assessing AFC equipment reliability was the lack of performance specifications. CWD contractually agreed to provide AFC equipment that met certain MTBF and MTTR criteria. However, these criteria did not apply to soft failures. In the absence of performance criteria for the combined effect of hard and soft failures, one alternative was to compare individual mezzanine reliabilities to the overall system* average. This approach identified those mezzanines which had reliabilities significantly below (or above) the system average. A T-test of proportions was utilized to compare mezzanines to the average of the remaining five mezzanines. (See Appendix 3 for a discussion of this statistic.) When the T-test was applied to the mezzanines at a 95 percent confidence level, two mezzanines had reliabilities significantly below the average of the other mezzanines. These were Silver Spring and Farragut West 17th Street. Section 4-2 contains an analysis of the types of failures occurring at the above-mentioned mezzanines.

Another method of assessing mezzanine farecard vendor reliabilities was to examine variations in vendor performance over time. System reliabilities were calculated on a monthly basis, and each mezzanine was compared to the monthly system average. Table 4-2 shows monthly mean transactions per failure

*System refers to all six mezzanines together.

TABLE 4-2. MONTHLY MEAN TRANSACTIONS PER FAILURE FOR FARECARD VENDORS BY MEZZANINE, 1978-1979

	1978			1979					
MEZZANINE	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR.	MAY	JUNE	AUG.
DuPont	N/A	98	80	534	1133	146	147	313	N/A	213
Brookland	N/A	215	N/A	75	116	166	N/A	215	119	72
Silver Spring	74	N/A	59	107	119	398	138	144	79	N/A
Farragut 17th St.	N/A	120	114	96	79	70	107	140	84	N/A
Farragut 18th St.	98	N/A	160	97	101	124	157	189	271	N/A
Rosslyn	147	N/A	60	104	182	111	211	202	172	N/A
TOTAL	104	126	77	107	148	130	163	185	118	102

N/A = data not available

for each mezzanine and the system total. Figure 4-3 shows system-wide monthly mean transactions per failure in bar chart form.

As Table 4-2 shows, mean transactions per failure varied substantially on a monthly mezzanine basis. There was a general trend of increasing vendor reliability beginning in January 1979. However, in June 1979, reliability decreased below the November 1978 level. Table 4-2 identifies the months which contributed to the low overall reliabilities of Silver Spring and Farragut West 17th Street.

Availability measures were calculated for all mezzanines on a total and monthly basis. Table 4-3 summarizes the overall availabilities for each mezzanine; 95 percent confidence intervals are shown in parentheses. Figure 4-4 shows availabilities in bar chart form.

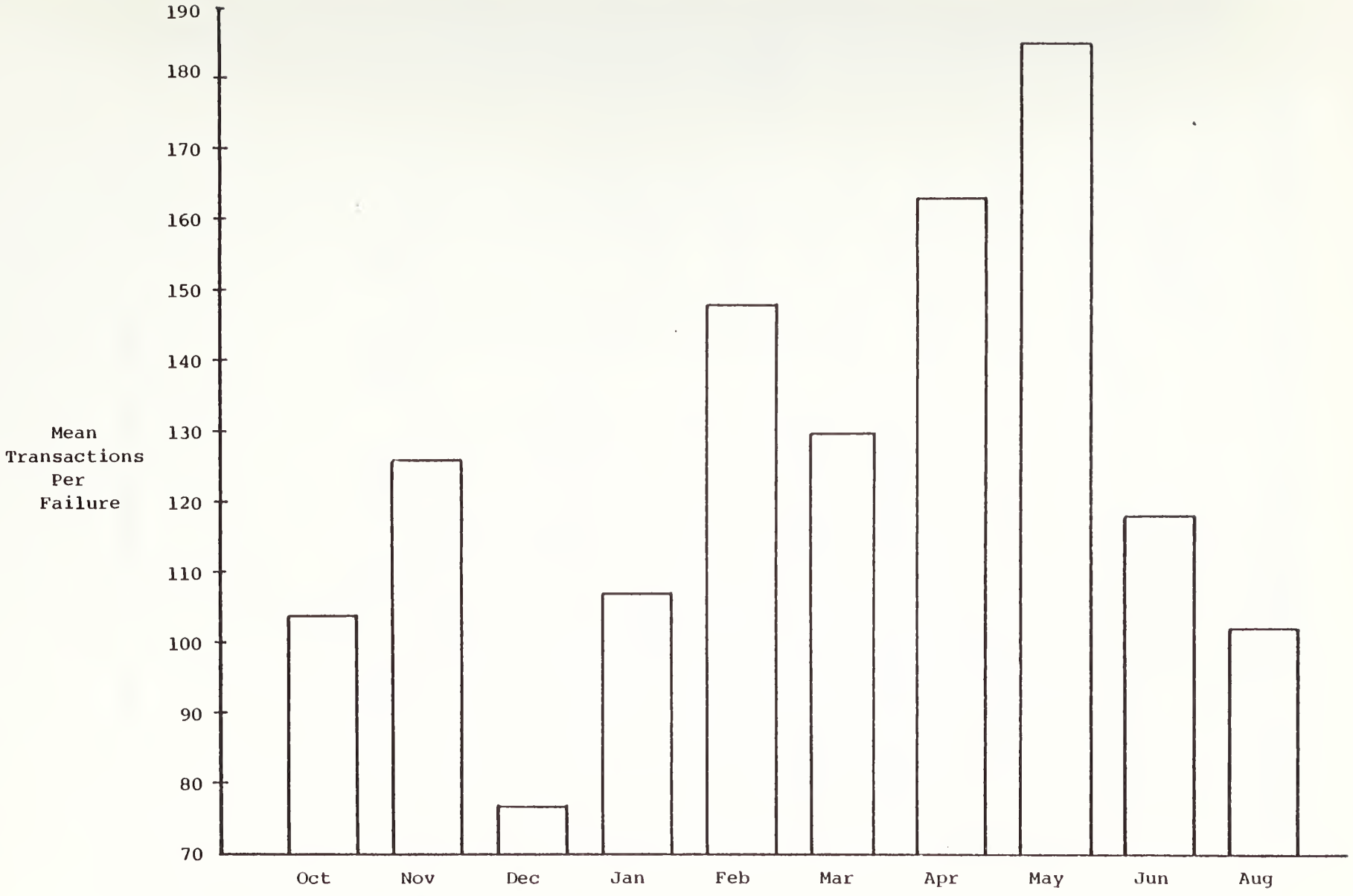


FIGURE 4-3. MONTHLY MEAN TRANSACTIONS PER FAILURE FOR FARECARD VENDORS[1], 1978-1979

[1] See Table 4-2 for a listing of the mezzanines included in each monthly average.

TABLE 4-3. FARECARD VENDOR AVAILABILITY BY MEZZANINE, 1978-1979

MEZZANINE	AVAILABILITY (PERCENT)
DuPont Circle	90.68 (90.27 - 91.09)
Brookland	81.46 (80.83 - 82.09)
Silver Spring	83.21 (82.81 - 83.61)
Farragut West - 17th Street	79.77 (79.22 - 80.32)
Farragut West - 18th Street	84.61 (84.11 - 85.11)
Rosslyn	84.50 (84.16 - 84.84)
TOTAL	84.08 (83.90 - 84.26)

( ) = 95 percent confidence intervals

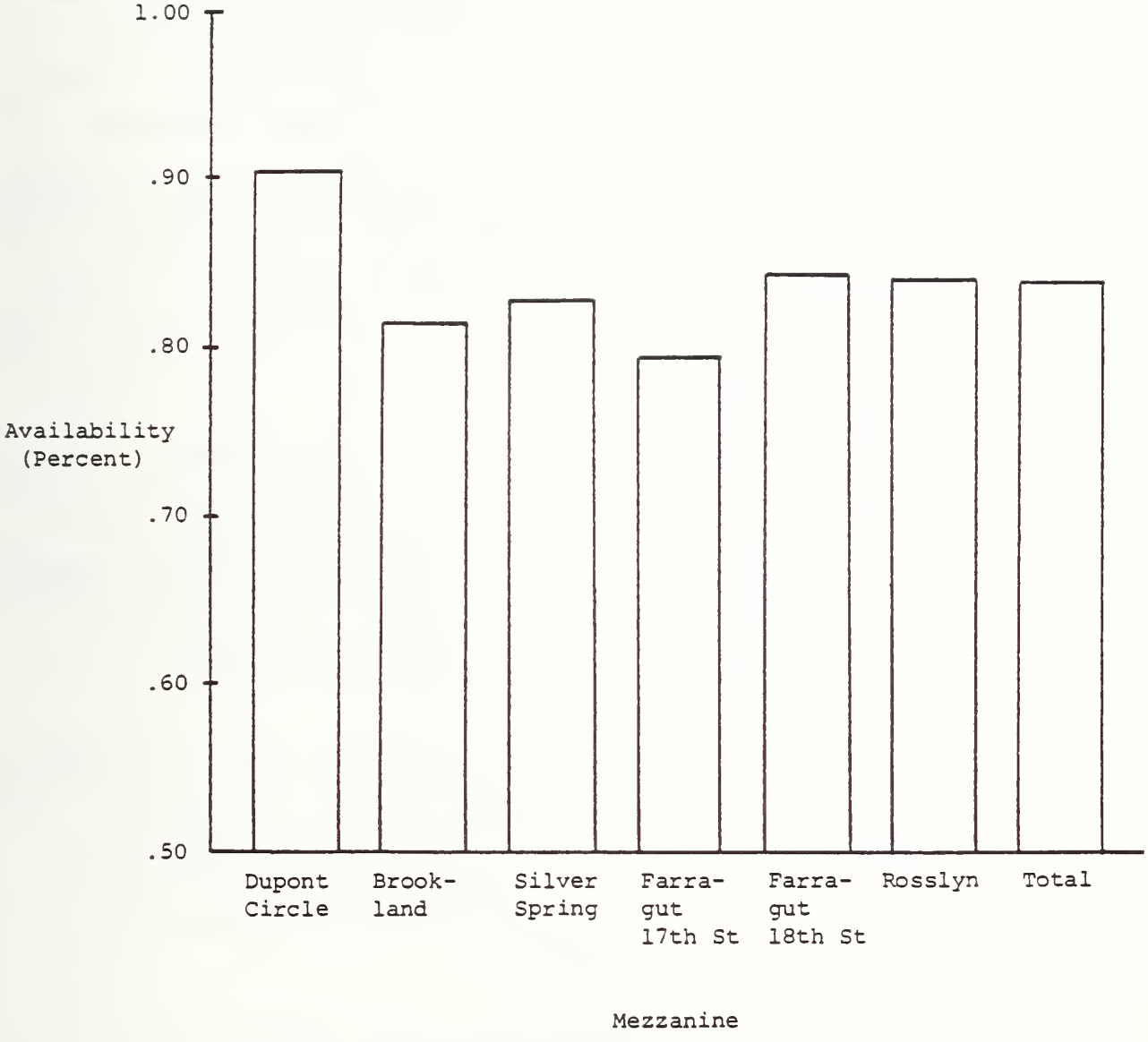


FIGURE 4-4. FARECARD VENDOR AVAILABILITY BY MEZZANINE, 1978-1979

Brookland, Silver Spring and Farragut West 17th St. had availabilities below the overall system mean. Brookland had vendors out of service for the entire monthly survey period on three occasions, and Silver Spring and Farragut West 17th St. had vendors out of service for the entire monthly survey on five occasions. The lengthy duration of some of the hard failures due to unavailability of spare parts contributed to the low availabilities at the three above-mentioned mezzanines.

Table 4-4 shows monthly mezzanine and total availabilities for farecard vendors. As with reliability, large monthly variations exist within as well as among mezzanines. Availabilities ranged from 54.13 percent to over 99 percent, and there was no apparent trend over time.

MTBF was also calculated for all mezzanines for both hard only and hard and soft failures combined. MTBF was calculated for hard failures for purposes of comparison with CWD contractual requirements. Hard and soft failures were combined to estimate a MTBF for all vendor failures. Table 4-5 and Figure 4-5 show the results of the MTBF calculations.

Caution should be exercised in comparing CWD's contractual requirements with the observed survey data for two reasons: the CWD requirements are for a total operating day as opposed to only peak-hours, and the hard failures observed during the 1978-1979 WMATA survey include money handling failures which were not included in CWD's survey.

As shown in Table 4-6, when all three measures of farecard vendor performance were compared, the mezzanines with the lowest mean transactions per failure also had the lowest availabilities. On the other hand, mezzanines with the lowest

TABLE 4-4. MONTHLY FARECARD VENDOR AVAILABILITIES BY MEZZANINE, 1978-1979 (PERCENT)

	1978			1979						
MEZZANINE	OCT.	NOV.	DEC.	JAN.	FEB.	MAR.	APR	MAY	JUNE	AUG.
DuPont	N/A	85.20	83.40	90.68	99.59	94.52	93.31	99.87	N/A	87.76
Brookland	N/A	69.90	N/A	92.69	88.39	98.43	N/A	69.69	60.37	92.92
Silver Spring	91.32	N/A	89.56	77.07	87.13	86.74	78.66	79.17	77.61	N/A
Farragut 17th St.	N/A	61.56	90.02	87.20	68.73	96.71	64.97	85.40	74.85	N/A
Farragut 18th St.	89.95	N/A	95.64	94.79	54.13	64.63	68.93	91.42	92.94	N/A
Rosslyn	81.79	N/A	79.06	89.53	78.32	96.56	96.29	79.40	72.56	N/A
TOTAL	86.93	71.85	86.28	87.17	78.71	93.44	85.05	83.13	76.76	90.51

TABLE 4-5. MEAN TIME* BETWEEN FARECARD VENDOR FAILURES BY MEZZANIME, 1978-1979

MEZZANINE	ALL FAILURES MTBF	HARD FAILURES MTBF	CWD MTBF SPECS.
DuPont Circle	3.30	19.05	920
Brookland	2.13	11.25	920
Silver Spring	1.86	35.37	920
Farragut West - 17th Street	1.58	13.75	920
Farragut West 0 18th Street	1.94	19.36	920
Rosslyn	1.88	23.46	920
TOTAL	1.96	19.80	920

*Time in Peak Hours

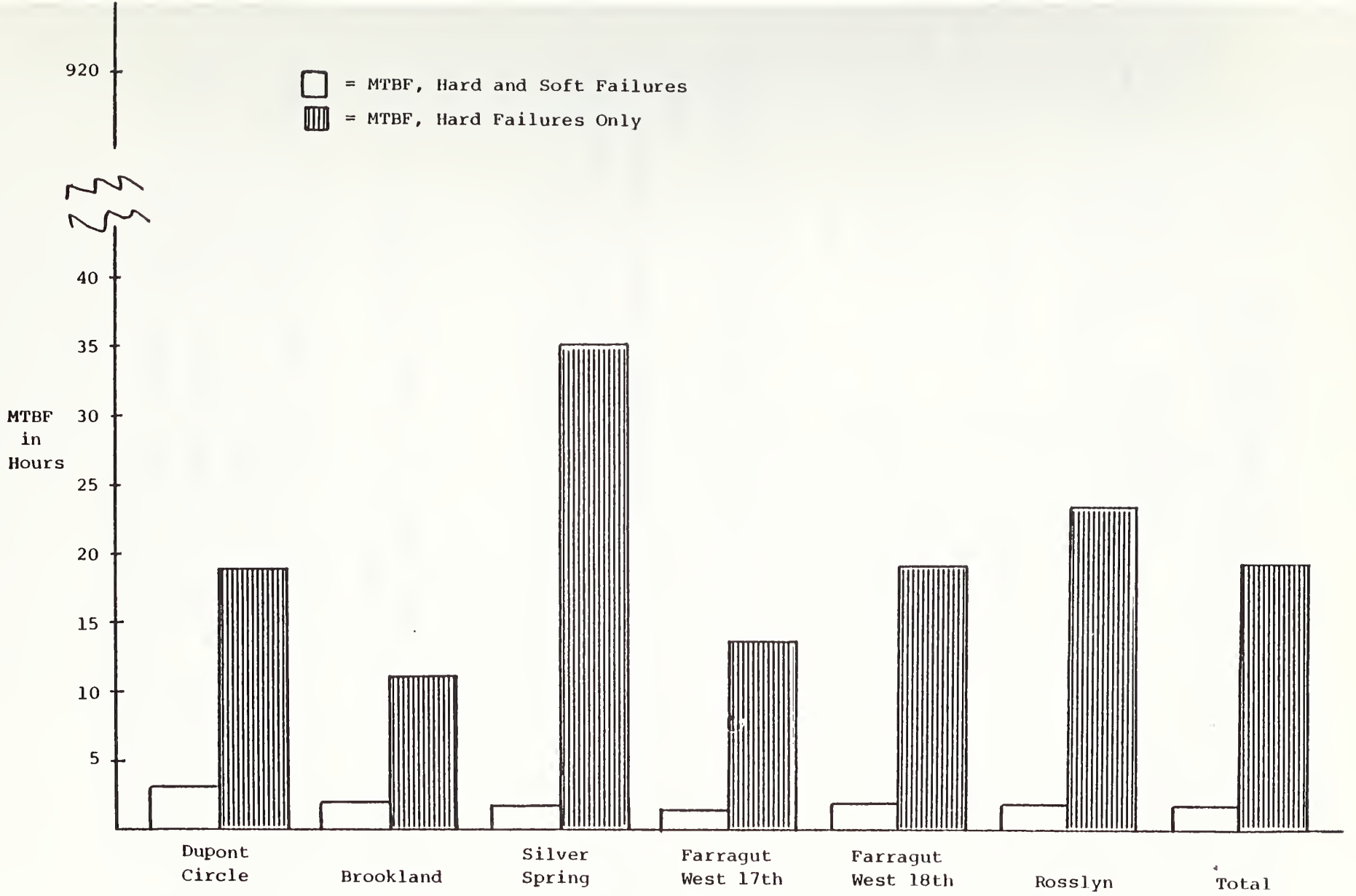


FIGURE 4-5. MTBF BY MEZZANINE FOR FARECARD VENDORS, 1978-1979

TABLE 4-6. SUMMARY OF FARECARD VENDOR PERFORMANCE BY MEZZANINE, 1978-1979

MEZZANINE	MEAN TRANSACTIONS PER FAILURE	AVAILABILITY	MTBF (HOURS)
DuPont Circle	192	90.68	3.30
Brookland	120	81.46	2.13
Silver Spring	99	83.21	1.86
Farragut West - 17th Street	97	79.77	1.58
Farragut West - 18th Street	129	84.50	1.94
Rosslyn	128	84.08	1.88
TOTAL	120	84.08	1.96

MTBF did not always have the lowest availabilities or mean transactions per failure. This comparison of the different measures indicates that no one performance measure alone provides all the information for an assessment of overall performance.

4.2 OVERALL ELEMENT PERFORMANCE FOR TICKET TRANSPORTS, COIN ACCEPTORS AND BILL VERIFIERS.

Several steps were taken to examine element performance and to compare and rank elements in terms of reliability, . First, overall reliabilities for each element were calculated and statistically ranked. Table 4-7 shows overall reliabilities and mean transactions per failure for each element, and Figure 4-6 shows these calculations graphically.

TABLE 4-7. RELIABILITY AND MEAN TRANSACTIONS PER FAILURE FOR FARECARD VENDOR ELEMENTS, 1978-1979

FARECARD VENDOR ELEMENT	RELIABILITY	MEAN TRANSACTIONS PER FAILURE
1. Ticket Transport	0.9973 (0.9970 - 0.9976)	376
2. Coin Acceptor	0.9988 (0.9986 - 0.9990)	844
3. Bill Verifier	0.9972 (0.9969 - 0.9975)	358

A T-test of proportions was utilized to compare and rank the element reliabilities. At a 99 percent confidence level, the coin acceptor was significantly more reliable than both the ticket transport and the bill verifier. No significant difference was found between the reliabilities of ticket transports and bill verifiers. Table 4-8 summarizes the element reliabilities by mezzanine.

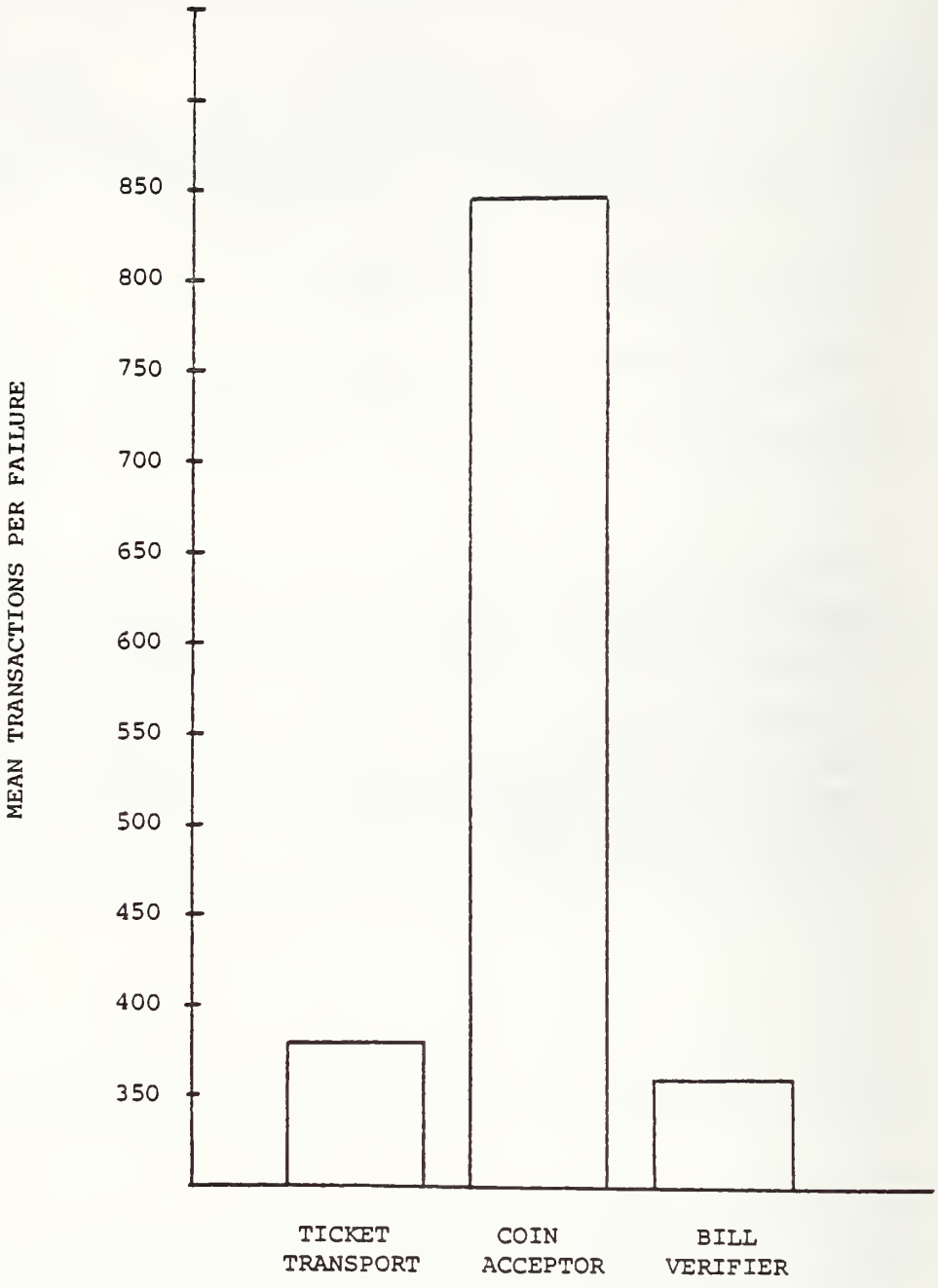


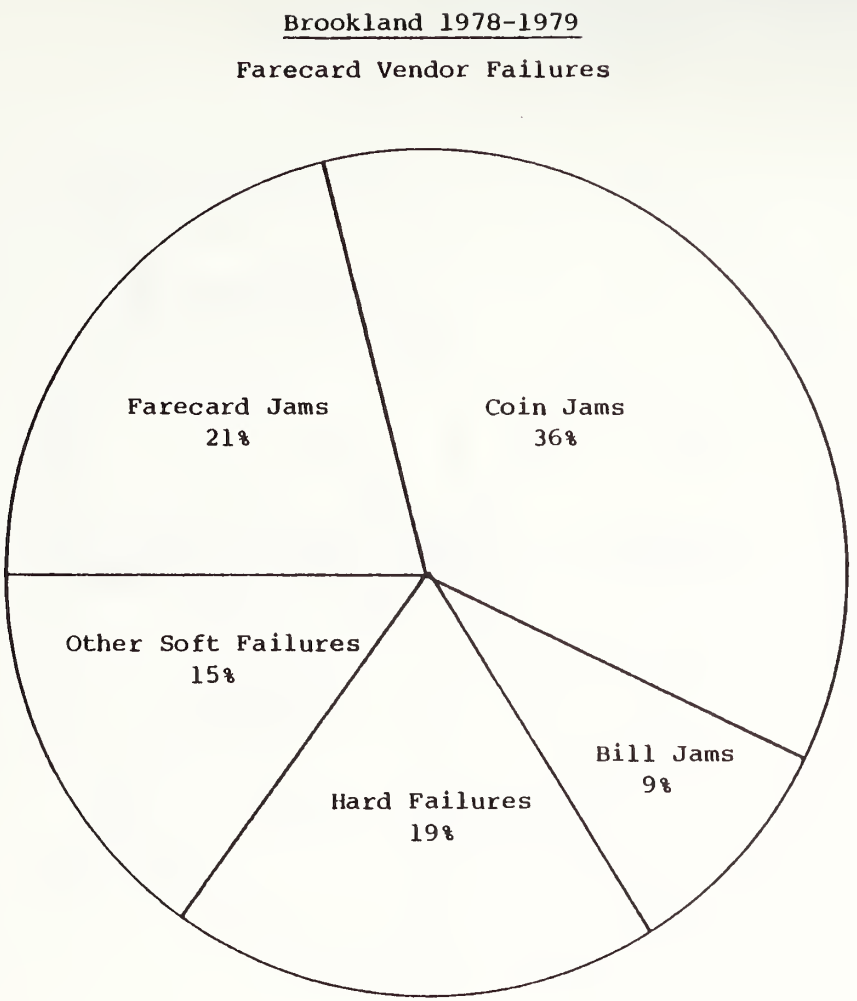
FIGURE 4-6. MEAN TRANSACTIONS PER FAILURE FOR FARECARD VENDOR ELEMENTS, 1978-1979

TABLE 4-8. RELIABILITY AND MEAN TRANSACTIONS PER FAILURE FOR FARECARD VENDOR ELEMENTS BY MEZZANINE, 1978-1979

MEZZANINE/ELEMENT	RELIABILITY	MEAN TRANSACTIONS PER FAILURE
DuPont Circle		
o Ticket Transport	0.9977	437
o Coin Acceptor	0.9994	1,717
o Bill Verifier	0.9991	1,061
Brookland		
o Ticket Transport	0.9983	580
o Coin Acceptor	0.9978	462
o Bill Verifier	0.9988	844
Silver Spring		
o Ticket Transport	0.9983	580
o Coin Acceptor	0.9978	462
o Bill Verifier	0.9986	722
Farragut West - 17th St.		
o Ticket Transport	0.9977	430
o Coin Acceptor	0.9991	1,129
o Bill Verifier	0.9938	161
Farragut West - 18th St.		
o Ticket Transport	0.9973	372
o Coin Acceptor	0.9992	1,250
o Bill Verifier	0.9968	312
Rosslyn		
o Ticket Transport	0.9972	363
o Coin Acceptor	0.9992	1,250
o Bill Verifier	0.9967	301

When the element reliabilities were examined by mezzanine, the coin acceptors consistently displayed the highest reliabilities at all mezzanines; the ticket transports had better reliabilities than the bill verifiers at three mezzanines while at the other three, the opposite was true. As previously mentioned, element reliabilities and mean transactions per failure were calculated on the basis of actual element usage. One alternative to examine element performance was to calculate the distribution of total failures. The pie charts in Figures 4-7 through 4-10 show each type of failure as a percentage of the total failures at each mezzanine and the total system.

On an individual mezzanine basis, farecard jams comprised the greatest percentage of total failures at four mezzanines; bill and coin jams were each the most numerous at one mezzanine. For the total system, fare card jams (32 percent) were the most frequent, followed by bill jams (25 percent) and coin jams (18 percent). The failure distribution indicates that while farecard jams are more numerous than bill jams, when the jams are normalized to usage, the impact on patrons (in terms of failures) is only slightly greater for farecard than for bill jams.



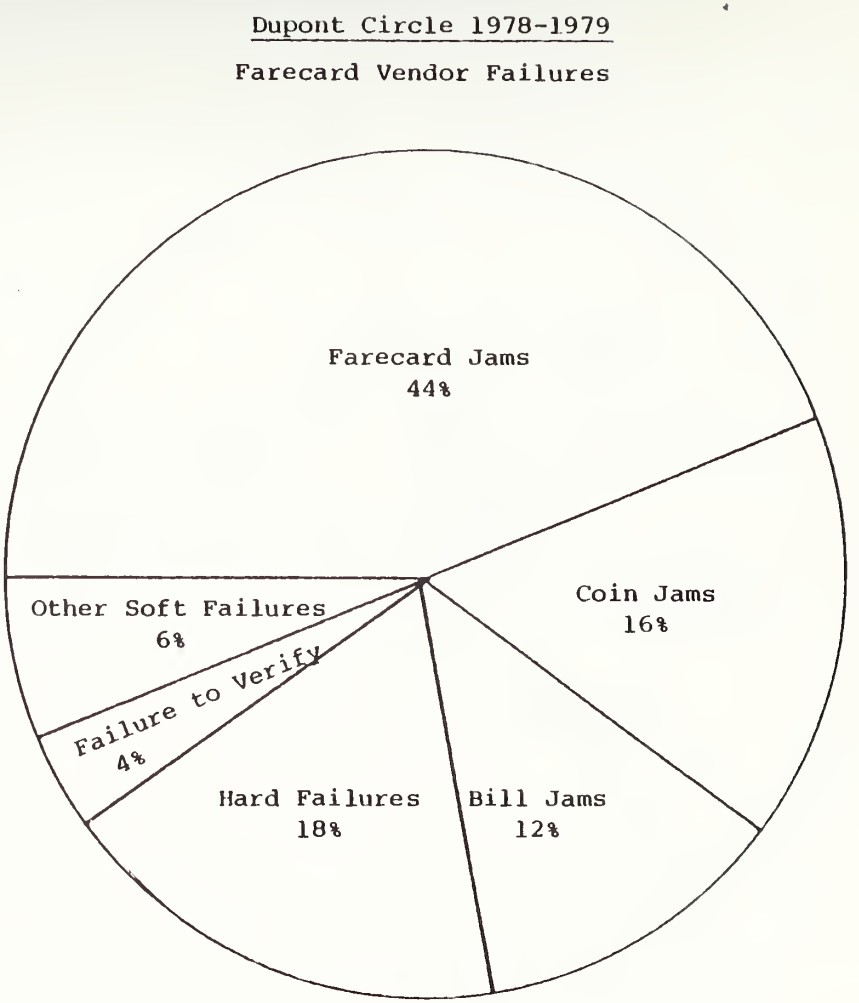


FIGURE 4-7. DISTRIBUTION OF FARECARD VENDOR FAILURES

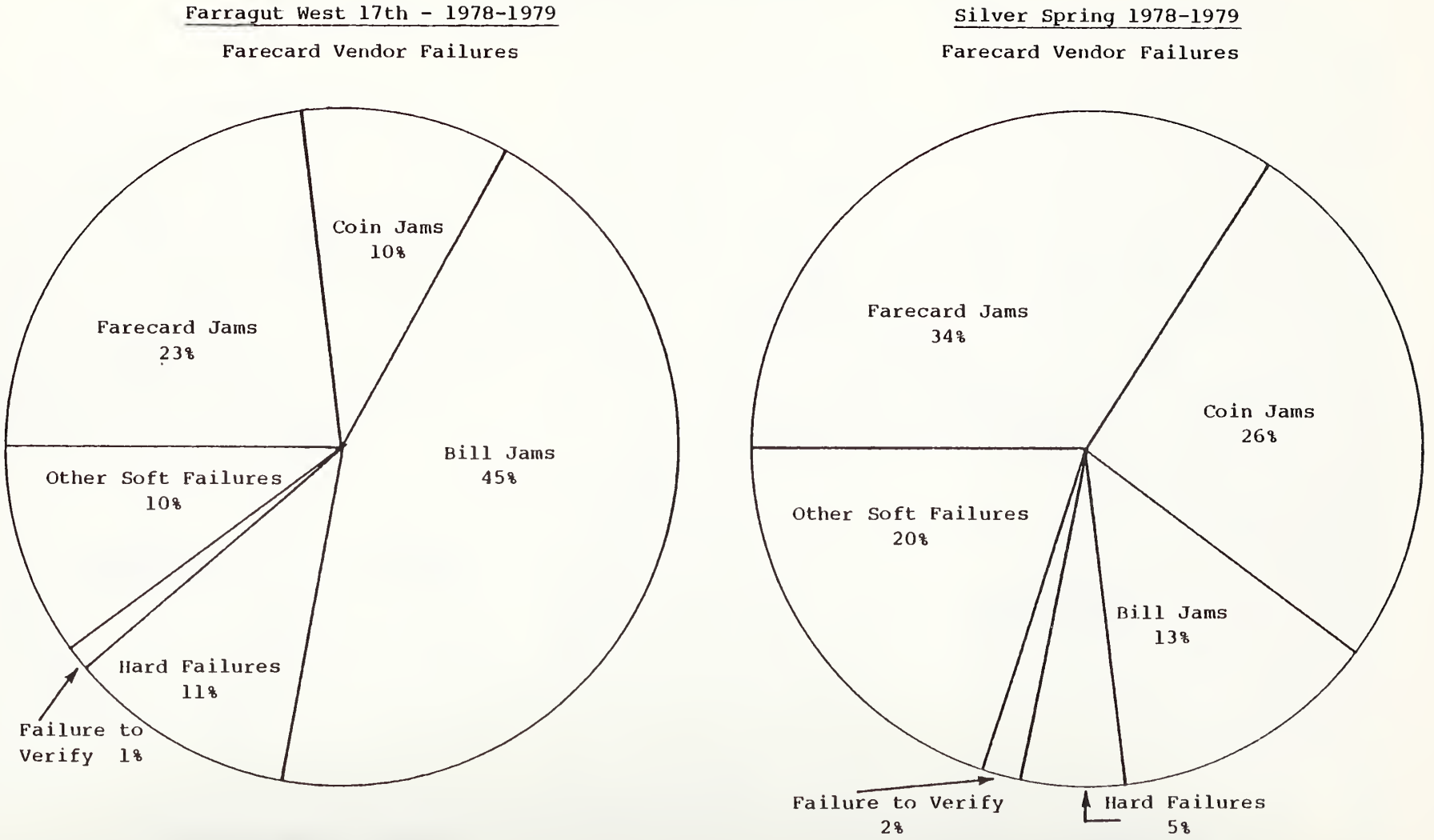


FIGURE 4-8. DISTRIBUTION OF FARECARD VENDOR FAILURES

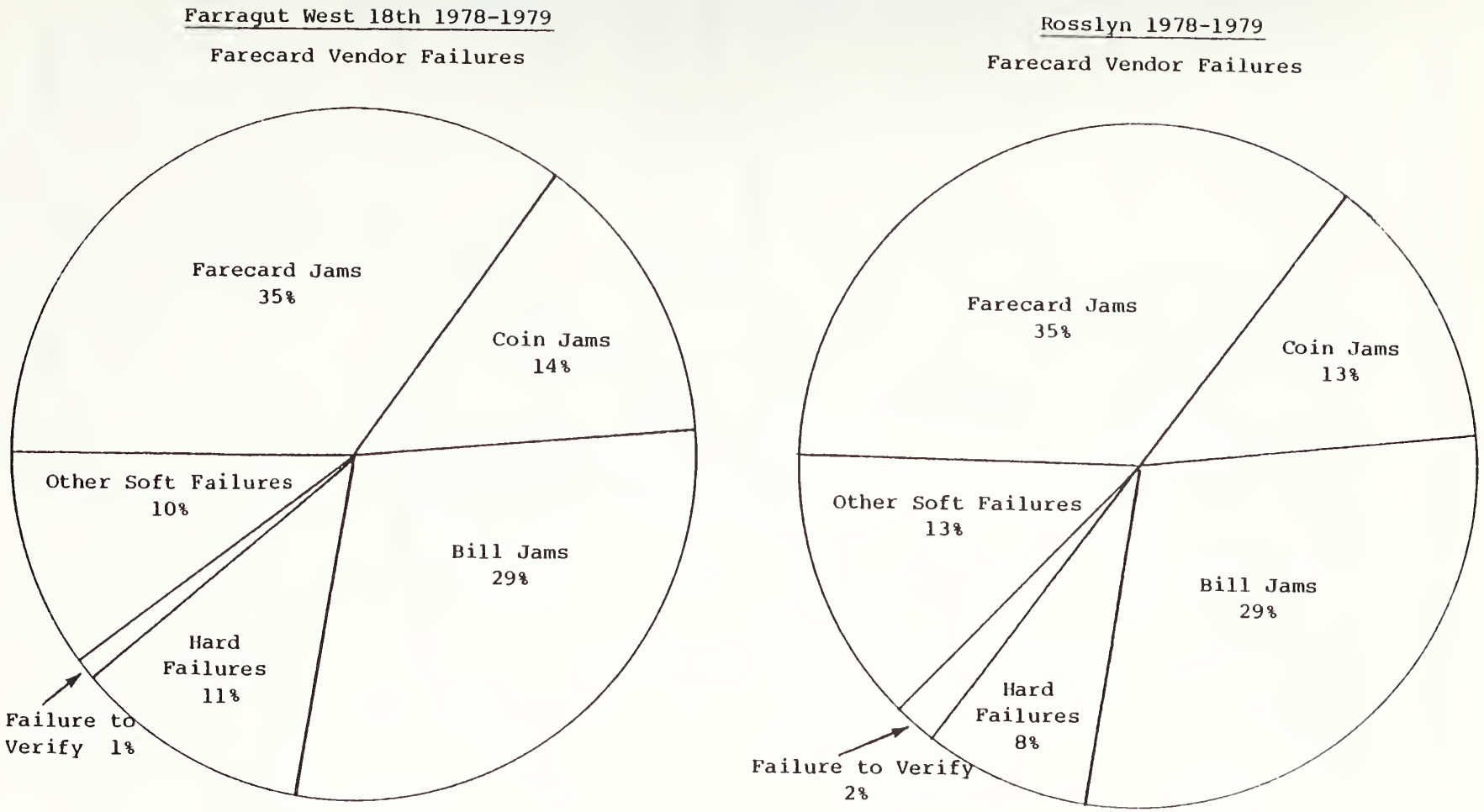


FIGURE 4-9. DISTRIBUTION OF FARECARD VENDOR FAILURES

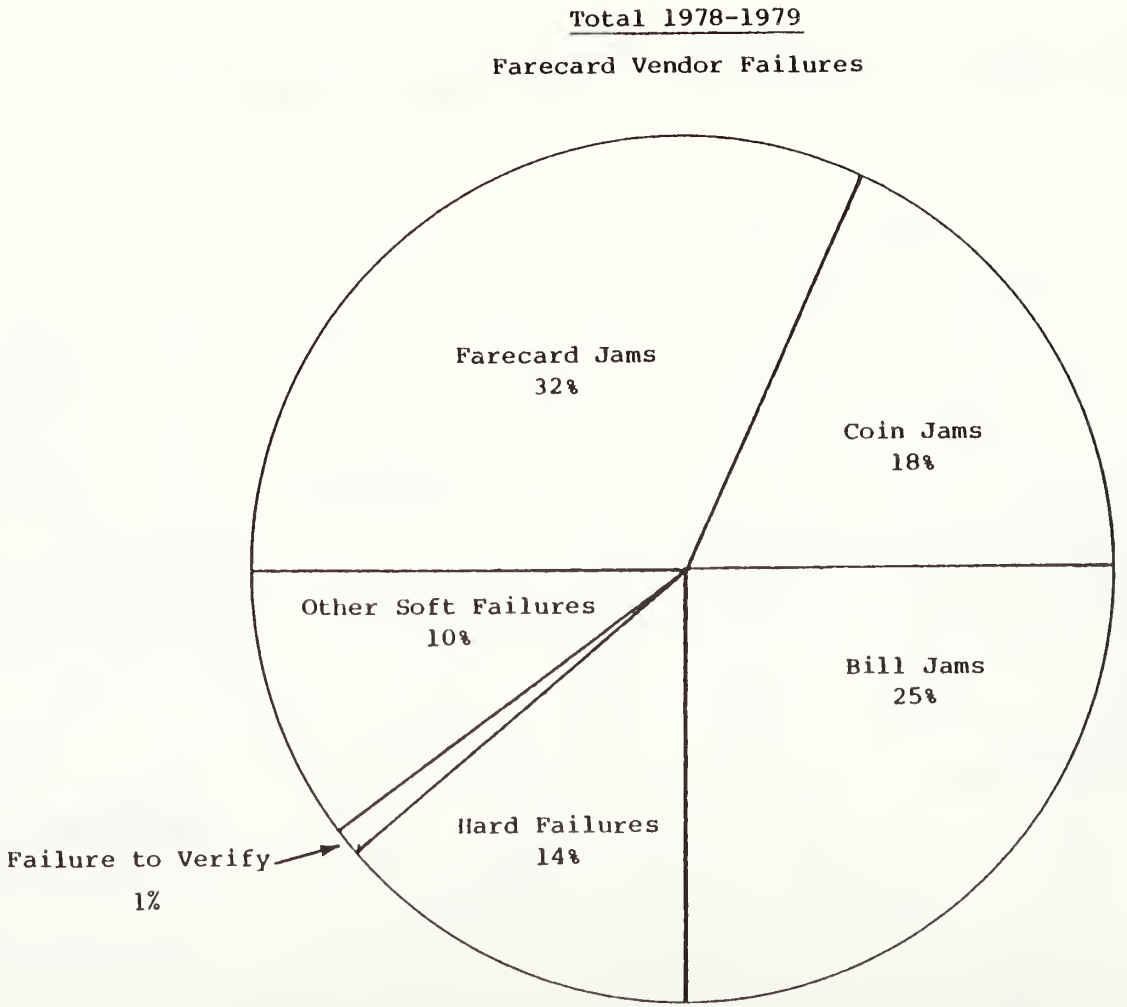


FIGURE 4-10. DISTRIBUTION OF TOTAL FARECARD VENDOR FAILURES, 1978-1979

4.3 FARECARD VENDOR-SPECIFIC: OVERALL AND ELEMENT PERFORMANCE

Reliability and availability measures were calculated for the forty farecard vendors individually. Reliabilities were also calculated on a monthly basis for each vendor and each element. T-tests of proportions were employed to identify farecard vendors with reliabilities significantly below the system average. Table 4-9 summarizes mean transactions per failure for vendors and elements.

As Table 4-9 shows, mean transactions per failure vary greatly among vendors for total and element reliabilities. Overall, mean transactions per failure ranged from 54 (vendor 40, Silver Spring), to 320 (vendor 31 at Farragut West 18th St.). Coin transactions per failure had the greatest range, from 185 (vendor 40, Silver Spring) to 6,036 (vendor 31, Farragut West 18th). Bill jams had the second largest range, from 104 to 4,295 bill transactions per failure (vendor 32, Farragut 17th and vendor 32, Silver Spring), while transactions per farecard jam ranged from 130 (vendor 40, Silver Spring) to 1,758 (vendor 42, Rosslyn).

When a T-test of proportions was utilized to test and compare overall and element reliabilities, certain vendors exhibited low reliabilities in more than one element. Table 4-10 summarizes the results of the T-tests. The vendors listed in each column displayed reliabilities significantly below (at 95 percent confidence) the overall mean for all vendors.

As Table 4-10 shows, low overall reliabilities (total failures) for the vendors are traceable to one or more low element reliabilities. To determine if the vendors identified in Table 4-9 consistently had low reliabilities over time, reliabilities were examined on a monthly basis for all vendors and elements. (Appendix 4 contains monthly data on all 40 farecard vendors.) Tables 4-11 to 4-18 summarize monthly

TABLE 4-9. MEAN TRANSACTIONS PER FAILURE FOR FARECARD VENDORS AND ELEMENTS BY MEZZANINE, 1978-1979

VENDOR	MEAN TRANSACTIONS PER FARECARD JAM	MEAN NUMBER OF COINS INSERTED PER COIN JAM	MEAN NUMBER OF BILLS INSERTED PER BILL JAM	MEAN TRANSACTIONS PER FAILURE
		DuPont Circle		
30	168	1,306	655	119
31	477	2,031	975	136
32	424	2,121	809	189
38	778	1,430	913	287
39	851	2,223	2,743	266
Total	437	1,717	1,061	192
		Brookland		
30	569	876	2,722	175
31	326	264	302	70
32	870	445	490	116
33	982	496	1,946	164
Total	580	462	844	120
		Silver Spring		
30	325	222	739	86
31	338	621	405	95
32	188	368	4.295	94
33	294	285	939	82
34	999	2,158	716	161
35	301	405	562	116
36	272	913	387	109
40	130	185	1,329	54
41	283	577	880	101
Total	294	435	722	99

TABLE 4-9. (Cont.)

VENDOR	MEAN TRANSACTIONS PER FARECARD JAM	MEAN NUMBER OF COINS INSERTED PER COIN JAM	MEAN NUMBER OF BILLS INSERTED PER BILL JAM	MEAN TRANSACTIONS PER FAILURE
		Farragut West - 17th Street		
30	528	2,241	225	141
31	415	1,369	199	101
32	293	2,302	104	64
33	243	462	135	76
34	1,307	875	195	131
35	687	1,425	159	106
Total	430	1,129	161	97
		Farragut West - 18th Street		
30	202	1,611	793	108
31	640	6,036	1,333	320
32	268	1,241	236	104
33	311	418	151	72
34	811	1,501	182	135
35	554	1,372	282	177
Total	372	1,250	312	129
		Rosslyn		
30	369	739	269	133
31	497	987	428	139
32	229	2,269	231	102
33	600	1,237	233	141
34	486	1,427	1,164	175
38	739	1,179	249	167
39	114	1,457	147	74
40	394	1,665	551	167
41	147	1,371	128	60
42	1,758	941	406	147
Total	363	1,250	301	128

TABLE 4-10. FARECARD VENDORS WITH RELIABILITIES SIGNIFICANTLY LESS (AT 95 PERCENT) THAN OVERALL MEAN

MEZZANINE*	TOTAL FAILURES	FARECARD JAMS	COIN JAMS	BILL JAMS	HARD AND "OTHER" FAILURES
Brookland	31**		31		
Silver Spring	33		33		
	40	40	40		40
			30		
Farragut West 17th St.	32			32	
	33			33	
Rosslyn	39	39			
	41	41		41	

*DuPont Circle and Farragut West 18th St. did not have any farecard vendors with significantly low reliabilities.

**Vendor number

TABLE 4-11. TOTAL AND ELEMENT MONTHLY RELIABILITIES AND MEAN TRANSACTIONS PER FAILURE: BROOKLAND, FARECARD VENDOR 31, 1978-1979

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
November	1.00	581/0	0.9986	714	0.9970	335	0.9983	581	0.9948	194
January	0.9916	120	0.9988	853	1.00	369/0	0.9983	598	0.9916	85
February	0.9962	261	0.9973	368	0.9968	312	0.9962	261	0.9866	75
March	1.00	516/0	0.9986	722	0.9878	82	0.9981	516	0.9884	86
May	Out of Service									
June	0.9973	373	0.9948	192	1.00	204/0	0.9839	62	0.9732	37
August	0.9971	348	0.9802	50	1.00	264/0	0.9971	348	0.9741	39
Total	0.9969	326	0.9962	264	0.9967	302	0.9959	245	0.9857	70

$T/J = \frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

$C/C = \frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

$B/B = \frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

$T/O = \frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

$T/T = \frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

$R = \text{Reliability} = \frac{\text{Successes}}{\text{Transactions}}$

TABLE 4-12. TOTAL AND ELEMENT MONTHLY RELIABILITIES AND MEAN TRANSACTIONS PER FAILURE: SILVER SPRING, FARECARD VENDOR 30, 1978-1979

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October	0.9912	114	0.9785	47	0.9965	288	0.9965	286	0.9615	26
December	0.9982	559	0.9968	310	1.00	543/0	0.9982	559	0.9928	140
January	0.9986	736	1.00	831/0	1.00	707/0	0.9986	736	0.9973	368
February	0.9971	351	1.00	854/0	1.00	655/0	1.00	702/0	0.9971	351
March	1.00	808/0	0.9978	449	0.9974	381	1.00	808/0	0.9950	202
April	0.9970	335	1.00	338/0	1.00	321/0	1.00	335/0	0.9970	335
May	0.9945	181	0.9946	184	0.9963	268	0.9926	136	0.9779	45
June	0.9966	296	0.9927	136	1.00	333/0	0.9966	296	0.9831	59
Total	0.9969	325	0.9955	222	0.9986	739	0.9980	506	0.9886	86

$T/J = \frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

$C/C = \frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

$B/B = \frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

$T/O = \frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

$T/T = \frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

$R = \text{Reliability} = \frac{\text{Successes}}{\text{Transactions}}$

TABLE 4-13. TOTAL AND ELEMENT MONTHLY RELIABILITIES AND MEAN TRANSACTIONS PER FAILURE: SILVER SPRING, FARECARD VENDOR 33, 1978-1979

Month	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October	Out of Service									
December	0.9908	108	0.9886	75	1.00	434/0	0.9945	180	0.9723	36
January	0.9957	235	1.00	608/0	1.00	400/0	0.9979	470	0.9936	157
February	0.9935	155	1.00	428/0	0.9956	230	0.9903	104	0.9806	52
March	1.00	189/0	1.00	307/0	1.00	154/0	1.00	189/0	1.00	189/0
April	1.00	308/0	1.00	337/0	1.00	310/0	0.9968	308	0.9968	308
May	1.00	592/0	1.00	392/0	0.9967	300	1.00	592/0	0.9966	296
June	0.9981	534	0.9924	133	1.00	690/0	0.9925	134	0.9831	59
Total	0.9966	294	0.9965	285	0.9989	939	0.9959	245	0.9878	82

$T/J = \frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

$C/C = \frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

$B/B = \frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

$T/O = \frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

$T/T = \frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

$R = \text{Reliability} = \frac{\text{Successes}}{\text{Transactions}}$

TABLE 4-14. TOTAL AND ELEMENT MONTHLY RELIABILITIES AND MEAN TRANSACTIONS PER FAILURE: SILVER SPRING, FARECARD VENDOR 40, 1978-1979

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October	1.00	444/0	1.00	517/0	1.00	450/0	0.9977	444	0.9977	444
December	0.9667	30	1.00	320/0	1.00	276/0	0.9926	135	0.9593	25
January	0.9974	383	0.9838	62	0.9976	411	0.9948	192	0.9739	38
February	No DADS Data									
March	1.00	206/0	0.9926	136	1.00	192/0	1.00	206/0	0.9903	103
April	Out of Service									
May	Out of Service									
June	Out of Service									
Total	0.9923	130	0.9946	185	0.9992	1329	0.9962	261	0.9816	54

$T/J = \frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

$C/C = \frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

$B/B = \frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

$T/O = \frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

$T/T = \frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

$R = \text{Reliability} = \frac{\text{Successes}}{\text{Transactions}}$

TABLE 4-15. TOTAL AND ELEMENT MONTHLY RELIABILITIES AND MEAN TRANSACTIONS PER FAILURE: FARRAGUT WEST - 17TH ST., FARECARD VENDOR 32, 1978-1979

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
November	0.9894	94	1.00	981/0	0.9952	208	0.9973	377	0.9814	54
December	0.9968	312	1.00	821/0	1.00	504/0	0.9968	312	0.9936	156
January	1.00	510/0	0.9984	618	0.9897	97	0.9961	255	0.9863	73
February	1.00	446/0	1.00	492/0	0.9908	110	0.9978	446	0.9910	112
March	0.9903	103	1.00	231/0	0.8571	7	0.9708	34	0.9029	10
April	0.9976	425	0.9982	554	0.9966	292	1.00	425/0	0.9929	142
May	1.00	86/0	1.00	67/0	0.9605	25	0.9767	43	0.9419	17
June	0.9954	216	1.00	840/0	0.9890	91	0.9969	324	0.9845	65
Total	0.9966	293	0.9996	2302	0.9904	104	0.9960	248	0.9845	64

$$T/J = \frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$$

$$C/C = \frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$$

$$B/B = \frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$$

$$T/O = \frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$$

$$T/T = \frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$$

$$R = \text{Reliability} = \frac{\text{Successes}}{\text{Transactions}}$$

TABLE 4-16. TOTAL AND ELEMENT MONTHLY RELIABILITIES AND MEAN TRANSACTIONS PER FAILURE: FARRAGUT WEST - 17TH ST., FARECARD VENDOR 33, 1978-1979

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
November	0.9968	310	1.00	189/0	0.9905	105	0.9978	465	0.9882	84
December	0.9907	108	0.9988	820	0.9911	113	1.00	650/0	0.9831	59
January	0.9967	305	0.9946	187	0.9885	87	0.9984	609	0.9803	51
February	0.9970	332	1.00	375/0	0.9834	60	1.00	332/0	0.9849	66
March	1.00	492/0	0.9979	477	1.00	403/0	1.00	492/0	0.9980	492
April	0.9779	45	1.00	109/0	0.9929	142	0.9779	45	0.9485	19
May	1.00	494/0	0.9981	517	1.00	403/0	1.00	494/0	0.9980	494
June	Out of Service									
Total	0.9959	243	0.9978	462	0.9926	135	0.9984	607	0.9868	76

$T/J = \frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

$C/C = \frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

$B/B = \frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

$T/O = \frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

$T/T = \frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

$R = \text{Reliability} = \frac{\text{Successes}}{\text{Transactions}}$

TABLE 4-17. TOTAL AND ELEMENT MONTHLY RELIABILITIES AND MEAN TRANSACTIONS PER FAILURE: ROSSLYN, FARECARD VENDOR 39, 1978-1979

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October	0.9993	1411	0.9981	520/0	0.9890	91	1.00	1411/0	0.9950	202
December	0.8333	6	1.00	96/0	1.00	45/0	0.9833	60	0.7833	5
January	0.9597	25	1.00	118/0	1.00	87/0	0.9919	124	0.9516	21
February	Data Unavailable									
March	1.00	130/0	1.00	216/0	1.00	86/0	0.9923	130	0.9923	130
April	0.9977	434	1.00	507/0	0.9954	219	1.00	434/0	0.9954	217
May	Out of Service									
June	Out of Service									
Total	0.9912	114	0.9993	1457	0.9933	147	0.9986	720	0.9866	74

T/J = Total Transactions / Total Farecard Jams

C/C = Total Coins Inserted / Total Coin Jams

B/B = Total Bills Inserted / Total Bill Jams

T/O = Total Transactions / Total "Other" Failures

T/T = Total Transactions / Total Jams and "Other" Failures

R = Reliability

TABLE 4-18. TOTAL AND ELEMENT MONTHLY RELIABILITIES AND MEAN TRANSACTIONS PER FAILURE: ROSSLYN, FARECARD VENDOR 41, 1978-1979

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October	0.9947	187	1.00	416/0	1.00	283/0	1.00	374/0	0.9947	187
December	0.9813	54	1.00	145/0	0.9880	84	0.9626	27	0.9346	15
January	0.9971	351	1.00	348/0	0.9934	153	1.00	351/0	0.9915	117
February	1.00	467/0	1.00	566/0	0.9941	170	1.00	467/0	0.9957	234
March	0.9701	36	1.00	411/0	0.9885	87	0.9970	335	0.9582	24
April	1.00	461/0	1.00	492/0	0.9874	80	1.00	461/0	0.9870	92
May	1.00	113/0	0.9972	182	No Transactions		0.9823	57	0.9646	28
June					Out of Service					
Total	0.9932	147	0.9993	1371	0.9922	128	0.9968	315	0.9832	60

$T/J = \frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

$C/C = \frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

$B/B = \frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

$T/O = \frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

$T/T = \frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

R = Reliability

reliability data for the farecard vendors identified in Table 4-10. The monthly analysis provided the following information:

1. Brookland:

   Farecard Vendor 31 - Coin acceptor reliabilities were low in June and August.

2. Silver Spring:

   Farecard Vendor 31 - Coin acceptor reliabilities were low in October, May and June.

   Farecard Vendor 40 - Ticket transport reliabilities were low in December, coin acceptor reliabilities were low in January and March, and "other" failures were high in December and January. In addition, vendor 40 was out of service during the months of April, May and June.

3. Farragut West - 17th Street

   Farecard Vendor 32 - Bill validator reliabilities were low in January, March, May and June.

   Farecard Vendor 33 - Bill validator reliabilities were low in November, January and February.

4. Rosslyn

   Farecard Vendor 39 - Ticket transport reliabilities were low in December and January, and vendor was out of service in May and June.

Farecard Vendor 41 - Ticket transport reliabilities were low in December and March, bill validator reliabilities were low in December, March and April, and the vendor was out of service in June.

Availability measures were calculated for each farecard vendor on a total and monthly basis. Table 4-19 shows availabilities for all vendors. A T-test of proportions was utilized to identify vendors with availabilities significantly below the system mean.

As Table 4-19 shows, 12 of the 40 vendors had availabilities significantly below the system mean. Vendor availabilities ranged from a low of 53.88 percent to almost 100 percent (vendor 30 at DuPont Circle). To determine if the vendors identified in Table 4-19 had consistently low availabilities over time, availabilities were examined on a monthly basis as shown in Tables 4-20 to 4-25. The monthly data yielded the following information:

1. DuPont Circle

   Farecard vendor 32 had a very low availability in November (36.67 percent), due to a broken bill validator and unavailable spare parts. Vendor 32 also had a low availability in December (70.75 percent) because the vendor was being repaired, and April was low due to problems with verifying farecards.

2. Brookland

   Farecard vendor 31 was out-of-service during the May survey period due to unavailable spare parts. It also had a low availability in June due to a broken coin vault.

TABLE 4-19. FARECARD VENDOR AVAILABILITIES, 1978-1979

LOCATION	VENDOR	AVAILABILITY
DuPont Circle	30	99.25
	31	90.94
	32	81.28*
	38	95.14
	39	86.80
Brookland	30	95.27
	31	75.21*
	32	79.54*
	33	75.80*
Silver Spring	30	93.93
	31	74.24*
	32	88.24
	33	84.90
	34	95.42
	35	70.46*
	36	95.76
	40	59.04*
	41	81.67*
Farragut West - 17th Street	30	92.71
	31	88.06
	32	87.16
	33	73.71*
	34	71.22*
	35	65.74*
Farragut West - 18th Street	30	77.24*
	31	93.36
	32	74.78*
	33	74.86*
	34	89.41
	35	88.75

*Availability significantly (95 percent confidence) below system mean.

TABLE 4-19. (Cont.)

LOCATION	VENDOR	AVAILABILITY
Rosslyn	30	80.79*
	31	81.99*
	32	87.42
	33	93.98
	34	92.44
	38	94.07
	39	53.88*
	40	88.11
	41	66.61*
	42	95.48

*Availability significantly (95 percent confidence) below system mean.

TABLE 4-20. DUPONT CIRCLE MONTHLY FARECARD VENDOR AVAILABILITIES, 1978-1979

	VENDOR				
MONTH	30	31	32	38	39
November	98.00	99.75	36.67	99.33	92.25
December	97.94	98.12	70.75	88.60	35.79
January	100.0	54.92	98.47	100.0	100.0
February	100.0	99.49	100.0	98.46	100.0
March	99.44	80.46	93.06	99.81	99.81
April	99.81	95.00	73.06	100.0	98.70
May	99.55	100.0	99.78	100.0	100.0
August	100.0	100.0	100.0	69.13	69.66
TOTAL	99.25	90.94	81.28	95.14	86.80

TABLE 4-21. BROOKLAND MONTHLY FARECARD VENDOR AVAILABILITIES, 1978-1979

	VENDOR			
MONTH	30	31	32	33
November	91.32	89.82	0.0	94.47
January	98.85	97.79	99.23	74.33
February	81.98	97.71	99.58	74.27
March	99.81	98.52	96.48	98.89
May	99.62	0.0	91.01	87.95
June	97.31	44.81	99.35	0.0
August	97.04	95.93	78.89	99.81
TOTAL	95.27	75.21	79.54	75.80

TABLE 4-22. SILVER SPRING MONTHLY FARECARD VENDOR AVAILABILITIES, 1978-1979

Month	Vendor								
	30	31	32	33	34	35	36	40	41
October	89.77	81.56	98.60	100.0	94.93	98.43	99.65	91.26	67.66
December	98.15	99.63	95.28	88.70	98.80	93.70	98.33	89.72	43.70
January	98.70	49.91	99.54	72.59	100.0	0.0	90.65	92.87	89.35
February	99.44	99.81	100.0	43.70	88.70	95.19	83.52	N/A	86.67
March	96.11	0.0	99.44	100.0	99.07	N/A	100.0	99.26	100.0
April	97.78	95.56	47.78	90.37	98.89	N/A	99.26	0.0	99.63
May	77.76	100.0	63.06	98.98	94.07	98.02	99.59	0.0	97.35
June	94.81	80.39	78.53	88.14	89.61	97.84	97.06	0.0	80.20
Total	93.93	74.24	88.24	84.90	95.42	70.46	95.76	59.04	81.67

N/A = Not Available

TABLE 4-23. FARRAGUT WEST, 17TH STREET MONTHLY FARECARD VENDOR AVAILABILITIES, 1978-1979

	VENDOR					
MONTH	30	31	32	33	34	35
November	98.43	97.22	79.44	94.26	0.0	0.0
December	75.83	97.59	92.87	90.65	95.09	88.06
January	95.36	61.29	89.01	93.15	85.08	99.29
February	93.70	76.67	95.74	76.67	0.0	69.63
March	99.52	93.90	89.73	99.61	99.81	100.00
April	81.48	88.33	87.04	32.96	100.00	0.0
May	98.87	93.98	93.05	99.81	95.11	84.00
June	97.04	91.02	77.87	0.0	87.96	95.19
TOTAL	92.71	88.06	87.16	73.71	71.22	65.74

TABLE 4-24. FARRAGUT WEST, 18TH STREET MONTHLY FARECARD VENDOR AVAILABILITIES, 1978-1979

	VENDOR					
MONTH	30	31	32	33	34	35
October	94.98	98.86	91.32	61.42	96.80	96.35
December	98.27	99.73	95.87	88.00	97.60	94.40
January	93.27	98.54	93.27	92.11	94.74	96.78
February	15.20	99.81	56.85	0.0	94.37	58.54
March	94.66	99.24	0.0	N/A	N/A	N/A
April	99.12	50.75	0.0	98.74	67.21	97.74
May	93.52	97.78	98.89	1.00	74.07	84.26
June	64.17	99.67	99.17	94.67	100.0	100.0
TOTAL	77.24	93.36	74.78	74.86	89.41	88.75

N/A = Not Available

TABLE 4-25. ROSSLYN MONTHLY FARECARD VENDOR AVAILABILITIES, 1978-1979

Month	Vendor									
	30	31	32	33	34	38	39	40	41	42
October	0.0	89.22	61.68	98.12	77.70	97.88	99.18	99.43	99.67	99.92
December	86.49	43.66	93.99	78.58	84.35	96.62	69.85	77.43	71.83	99.18
January	94.30	97.11	97.26	86.78	93.69	76.72	63.87	99.47	64.59	98.18
February	98.13	85.45	95.90	98.51	96.64	76.49	No Data	0.0	98.13	55.60
March	98.60	98.34	89.86	98.25	99.74	99.21	99.62	99.21	85.31	99.83
April	99.12	83.36	91.29	97.36	97.36	98.86	98.66	98.77	98.94	99.65
May	97.13	91.20	99.12	99.38	98.86	97.71	0.0	82.22	38.73	95.69
June	84.51	66.90	89.96	98.42	94.01	98.94	0.0	98.42	0.0	93.13
Total	80.79	81.99	87.42	93.98	92.44	94.07	53.88	88.11	66.61	95.48

Farecard vendor 32 was out of service in November due to a broken coin acceptor and printer.

Farecard vendor 33 was out of service in June due to unavailable spare parts, and it had low availabilities during January and February due to coin and farecard problems respectively.

3. Silver Spring

Farecard vendor 31 was out of service during the March survey due to unavailable spare parts, and it had a low reliability (49.91) in January due to a broken bill validator.

Farecard vendor 35 was out of service in January due to unavailable spare parts.

Farecard vendor 40 was out of service in April, May and June (no reason listed on survey sheets).

Farecard vendor 41 had low availabilities in October (67.66 percent) and December (43.70 percent) due to lengthy out-of-service periods (no reason given on survey sheets).

4. Farragut West 17th Street

Farecard vendor 33 was out of service in June (no reason listed on survey sheets) and it had a low availability in April (32.96 percent) due to a lengthy out-of-service period (no reason given on survey sheets).

Farecard vendor 34 was out of service in November and February (no reason listed on survey sheets).

Farecard vendor 35 was out of service during the November survey due to a full money container, and out of service in April (no reason listed on survey sheet).

5. Farragut West - 18th Street

Farecard vendor 30 had a low availability in February (15.20 percent) due to constant farecard jams, and a low availability in June due to unavailable spare parts.

Farecard vendor 32 was out of service in March and April due to unavailable spare parts, and it had a low availability in February due to the combined effect of bill jams and failures to verify tickets.

Farecard vendor 33 was out of service in February due to unavailable spare parts, and it had a low availability in October (61.42 percent) due to problems with the bill transport and unavailable spare parts.

6. Rosslyn

Farecard vendor 30 was out of service in October (no reason given on survey sheets).

Farecard vendor 31 had low availabilities in December (43.66 percent) and in June (66.90 percent) due to numerous out-of-service periods (no reason listed on survey sheets).

Farecard vendor 39 was out of service in May and June due to constant farecard jams and unavailable parts.

Farecard vendor 41 was out of service in June due to a broken bill validator. It also had low availabilities in January and May due to numerous jams and out-of-service periods.

The detailed monthly analysis of availability indicates that a substantial portion of the vendors' down time (out-of-service time) resulted from unavailable spare parts. Other lengthy out-of-service periods were not documented on the survey sheets, so it is difficult to isolate other major causes of down time. Soft failures such as ticket, coin and bill jams averaged a little over 8 minutes each while hard failures averaged over 116 minutes each. Availability for the vendors could be increased substantially if the average down time per hard failure could be reduced.

The final measure examined for the analysis of farecard vendor performance was MTBF. Table 4-26 shows MTBF for all vendors for the total number of failures. The mean number of transactions per failure and availabilities are also shown in Table 4-26 for purposes of comparison.

4.4 SUMMARY

The findings of the assessment of WMATA's farecard vendor performance may be summarized as follows:

1. Overall Farecard Vendor Performance by Mezzanine

   The mean number of transactions per failure at each mezzanine ranged from 97 to 192, with an overall mean of 120 transactions per failure. Two mezzanines, Silver

TABLE 4-26. MTBF, MEAN TRANSACTIONS PER FAILURE AND AVAILABILITY FOR TOTAL FARECARD VENDOR FAILURES, 1978-1979

LOCATION	VENDOR	T/F	A	MTBF
DuPont Circle	30	119	99.3	2.7
	31	136	90.9	3.1
	32	189	81.3	3.6
	38	287	95.1	3.4
	39	266	86.8	4.1
Brookland	30	175	95.3	2.0
	31	70	75.2	1.3
	32	116	79.5	1.8
	33	164	75.8	2.9
Silver Spring	30	86	93.9	1.2
	31	95	74.2	2.1
	32	94	88.2	1.5
	33	82	84.9	1.9
	34	161	95.4	2.0
	35	116	70.5	1.9
	36	109	95.8	2.2
	40	54	59.0	2.4
	41	101	81.7	2.4
Farragut West - 17th Street	30	141	92.7	1.9
	31	101	88.1	1.7
	32	64	87.2	1.2
	33	76	73.7	1.2
	34	131	71.2	1.9
	35	106	65.7	2.2
Farragut West - 18th Street	30	108	77.2	1.8
	31	320	93.4	4.0
	32	104	74.8	1.6
	33	72	74.9	1.4
	34	135	89.4	2.2
	35	177	88.8	2.2

T/F = Mean Transactions per Failure

A = Availability

TABLE 4-26. (Cont.)

LOCATION	VENDOR	T/F	A	MTBF
Rosslyn	30	133	80.8	2.0
	31	139	82.0	1.7
	32	102	87.4	1.2
	33	141	94.0	1.6
	34	175	92.4	1.9
	38	167	94.1	2.3
	39	74	53.9	1.8
	40	167	88.1	2.9
	41	60	66.6	1.9
	42	147	95.5	3.1
MEAN		120	84.1	2.0

T/F = Mean Transactions per Failure

A = Availability

Spring and Farragut West 17th St. had reliabilities significantly lower than the system average. No monthly trend in reliabilities was identifiable. Availabilities ranged from 79.8 percent to 90.7 percent, with a system mean of 84.1 percent. Monthly variation in availability within and among mezzanines followed no apparent trend.

2. Overall Element Performance

The coin acceptor element was significantly more reliable than both the ticket transport and the bill verifier. No significant difference was found between the reliabilities of the ticket transport and the bill verifier. On an individual mezzanine basis, farecard jams comprised the greatest percentage of total failures at four mezzanines; bill and coin jams were each the most numerous at one mezzanine. Overall, farecard jams (32 percent) were most numerous, followed by bill jams (25 percent) and coin jams (18 percent).

3. Farecard Vendor-Specific: Overall and Element Performance

Low overall reliabilities in specific farecard vendors were traceable to one or more low element reliabilities. Of the forty vendors examined, seven had significantly low (compared to the system average) reliabilities. Eighteen vendors had availabilities significantly less than the system mean. Of these eighteen, five of the vendors also had the lowest reliabilities. The major cause of the low vendor availabilities was the lack of an adequate supply of spare parts, and the lengthy out-of-service periods which were not attributed to a specific element on the survey sheets.

5. ANALYSIS OF RETROFIT ELEMENT PERFORMANCE

As part of CWD's AFC improvement program, a series of improvements (retrofits) to elements of the AFC equipment were implemented. The first group of retrofits was installed in December 1978 and January 1979. These initial improvements were directed at the ticket transport and they involved a series of modifications to the hinges, rollers and printers. A second group of retrofits was installed in February 1980. This group consisted of two types of retrofits: Retrofit A, changes to the ticket transport, and Retrofit B, changes to the ticket transport, coin acceptor and bill validator. This chapter assesses the effectiveness of the retrofits in improving AFC equipment performance.

5.1 1978-1979 RETROFIT PERFORMANCE

Retrofit ticket transports were installed at seven mezzanines in selected farecard vendors. The mezzanines and vendors tested for performance improvements are listed below.

1. DuPont Circle - Vendors 30 to 32, 38 and 39.

2. Farragut West, 17thSt. - Vendors 31 and 32.

3. Farragut West, 18thSt. - Vendors 33 to 35.

4. Rosslyn - Vendors 30 to 34, 38 and 39.

To assess the performance of the retrofit ticket transports, a statistical analysis was performed in two ways. First, pre- and post-reftrofit reliabilities (i.e., all months before and all months after) were calculated and compared.

Table 5-1 shows mean transactions per farecard jam for all months before and after the retrofits.

Pre- and post-retrofit reliabilities were compared by utilizing a T-test of proportions to determine if increases in reliabilities were significant. As Table 5-1 shows, only vendors at Rosslyn showed statistically significant improvements

TABLE 5-1. PRE- AND POST-RETROFIT MEAN TRANSACTIONS PER FARECARD JAM FOR FARECARD VENDORS, 1978-1979

LOCATION	VENDOR	MEAN TRANSACTIONS PER FARECARD JAM: PRE-RETROFIT	MEAN TRANSACTIONS PER FARECARD JAM: POST-RETROFIT
DuPont Circle	30	92	119
	31	270	345
	32	294	476
	38	333	1,000
	39	769	909
Farragut West - 17th Street	31	256	909
	32	250	345
Farragut West - 18th Street	33	303	313
	34	500	1,111
	35	357	1,111
Rosslyn	30	81	1,000**
	31	200	769*
	32	121	313*
	33	143	588**
	34	122	2,500**
	38	714	769
	39	82	667**

*Significant Improvement over Pre-Retrofit at 95 Percent Confidence Level.

**Significant Improvement over Pre-Retrofit at 99 percent Confidence Level.

in the mean number of transactions per farecard jam. While all vendors in the test sample showed improvements in reliability, only improvements in vendor reliabilities at Rosslyn can be attributed to the retrofits.

The second method of examining retrofit vendor performance was to compare retrofit to non-retrofit farecard vendors at each mezzanine. Table 5-2 shows the results of the retrofit versus non-retrofit comparison. DuPont Circle had no non-retrofit vendors.

TABLE 5-2. RETROFIT VERSUS NON-RETROFIT FARECARD VENDORS: COMPARISON OF MEAN TRANSACTIONS PER FARECARD JAM, 1978-1979

LOCATION	MEAN TRANSACTIONS PER FARECARD JAM	
	NON-RETROFIT	RETROFIT
Farragut West - 17th Street	625	500
Farragut West - 18th Street	294	667*
Rosslyn	357	558*

*Significant at 95 Percent Confidence Level

A T-test of proportions was utilized to determine if the improvements were significant. As Table 5-2 shows, the Rosslyn and Farragut West - 18th Street mezzanines demonstrated improvements that were significant at the 95 percent level. At the Farragut West -17th Street mezzanine, non-retrofit vendors had higher reliabilities than the retrofit vendors. Overall, reliabilities increased due to the retrofits, but they did not display consistent results.

5.2 1980 RETROFIT PERFORMANCE

The 1980 retrofit performance data for Farragut West, 17th St. (A), Rosslyn (A) and Farragut West 18th St. (B) were analyzed at three levels of detail: 1) overall equipment performance for gates, farecard vendors and add-fares; 2) overall element performance for ticket transports, coin acceptors and bill validators; and 3) equipment specific: overall and element performance. To determine if Retrofits A and B produced significant improvements in AFC equipment performance, pre- and post-retrofit data were compared. For farecard vendors, the 1978-1979 system data were compared with 1980 performance measures, and for gates and add-fares, a two-month sample of the 1978-1979 data (January and February) was utilized for comparison purposes.

The 1980 performance data were divided into three groups:

1. Data on AFC equipment performance covering the last week of February and the first week of March, 1980. This set of data covers the time period immediately following the installation of the retrofits and it is referred to as February retrofit data.

2. Performance data for the remainder of March 1980 for Farragut West, 17th St. (A), and Farragut West, 18th St. (B). The data are referred to as March retrofit data.

3. Performance data for the month of April for all three previously-mentioned retrofit mezzanines are referred to as April retrofit data.

The retrofit performance data were utilized to identify and quantify relative improvements in WMATA's AFC equipment performance (reliability and availability), to compare peak versus off-peak performance and to develop a failure distribution analysis.

5.2.1 Overall Equipment Performance

Reliability, measured in mean number of transactions per failure, is shown in Table 5-3 for all gates, vendors, and add-fares. February, March and April data are shown individually and together for Retrofits A and B. Figure 5-1 shows mean transactions per failure graphically; Retrofit A and Retrofit B data are grouped together for the three-month survey period (February through April 1980). Asterisks on the transactions in Table 5-3 indicate statistically significant improvements over the 1978-1979 equipment reliabilities. Table 5-4 shows AFC equipment availability expressed as a percentage of total survey operating time. Figure 5-2 shows the percentages graphically. Confidence intervals for reliabilities and availabilities are contained in Appendix 5.

The reliability and availability of equipment with Retrofit B significantly increased over 1978-1979. Retrofit A equipment experienced a significant improvement in gate reliability, while farecard vendors had a slight increase and add-fares had a decrease in reliability from 1978-1979.

Availability for Retrofit A equipment increased significantly for gates and farecard vendors; add-fares showed a decrease in availability. All of the Retrofit B equipment achieved a 95 percent availability requirement while only gates for Retrofit A met this availability. The reliability and availability of all Retrofit B equipment was significantly better than that of Retrofit A equipment.

Table 5-5 shows mean time between failures (MTBF) for all AFC equipment; Figure 5-3 presents this data graphically. All AFC equipment with Retrofit B experienced significant improvements in MTBF, with gates having the greatest increase. For AFC equipment with Retrofit A, gates and add-fares experienced significant improvement in MTBF for Retrofit A, while farecard vendors showed a decrease. Retrofit B showed a significant increase in MTBF over Retrofit A.

TABLE 5-3. COMPARISON OF MEAN TRANSACTIONS PER FAILURE FOR AFC EQUIPMENT: 1978-1979 SURVEY (PRE-RETROFIT) AND 1980 SURVEY (RETROFITS A AND B) - TOTAL EQUIPMENT RELIABILITY

AFC EQUIPMENT	MEAN TRANSACTIONS PER FAILURE[1]								
	PRE-RETROFIT	RETROFIT A				RETROFIT B			
		FEBRUARY	MARCH[2]	APRIL	TOTAL	FEBRUARY	MARCH	APRIL	TOTAL
Gates	502	525	3,496**	802**	712**	1,596**	4,865**	5,216**	2,220**
Farecard Vendors	120	115	109	197**	133	279**	189**	310**	265**
Add-fares	96	72	53	142	84	132*	313**	386**	174**

[1]Includes all hard and soft failures
[2]Farragut West, 17th St. only

*Significant improvement over 1978-1979 at 95 percent confidence level
**Significant improvement over 1978-1979 at 99 percent confidence level

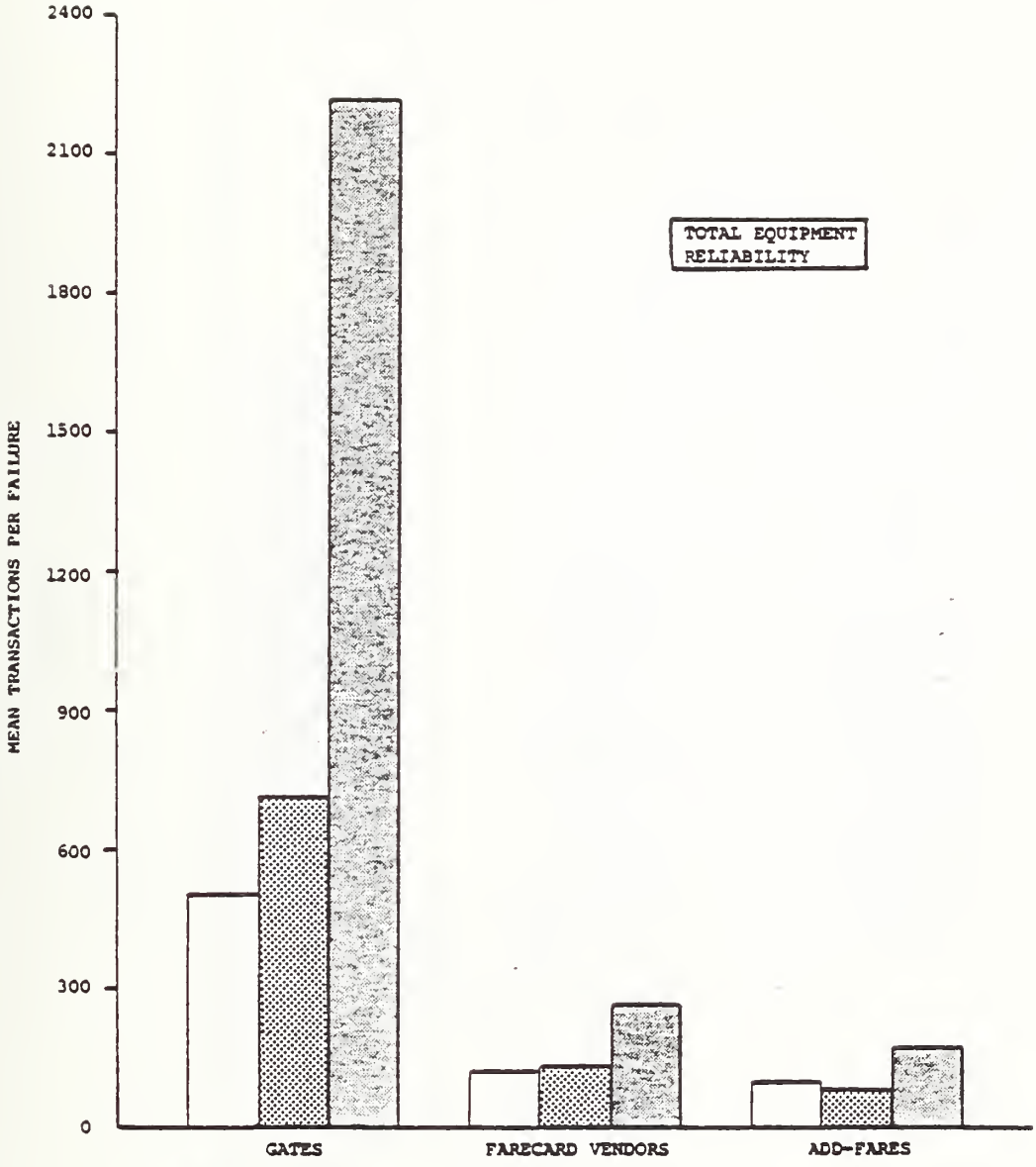


FIGURE 5-1. COMPARISON OF MEAN TRANSACTIONS PER FAILURE FOR AFC EQUIPMENT: 1978-1979 SURVEY (PRE-RETROFIT) AND 1980 SURVEY (RETROFITS A & B)

PRE-RETROFIT

RETROFIT A

RETROFIT B

TABLE 5-4. COMPARISON OF AFC EQUIPMENT AVAILABILITIES: 1978-1979 SURVEY (PRE-RETROFIT) AND 1980 SURVEY (RETROFITS A AND B) - TOTAL EQUIPMENT AVAILABILITY

AFC EQUIPMENT	EQUIPMENT AVAILABILTY								
		RETROFIT A				RETROFIT B			
	PRE-RETROFIT	FEBRUARY	MARCH[1]	APRIL	TOTAL	FEBRUARY	MARCH	APRIL	TOTAL
Gates	92.71	95.30**	92.42	97.02**	95.54**	94.92**	98.87**	93.11	95.43**
Farecard Vendors	84.08	89.22**	92.07**	94.82**	91.61**	97.51**	96.32**	98.02**	97.61**
Add-fares	96.17	91.31	94.17	96.23	93.33	98.08**	99.49**	99.72**	98.67**

[1]Farragut West, 17th Street only

**Significant improvement over 1978-1979 at 99 percent confidence level

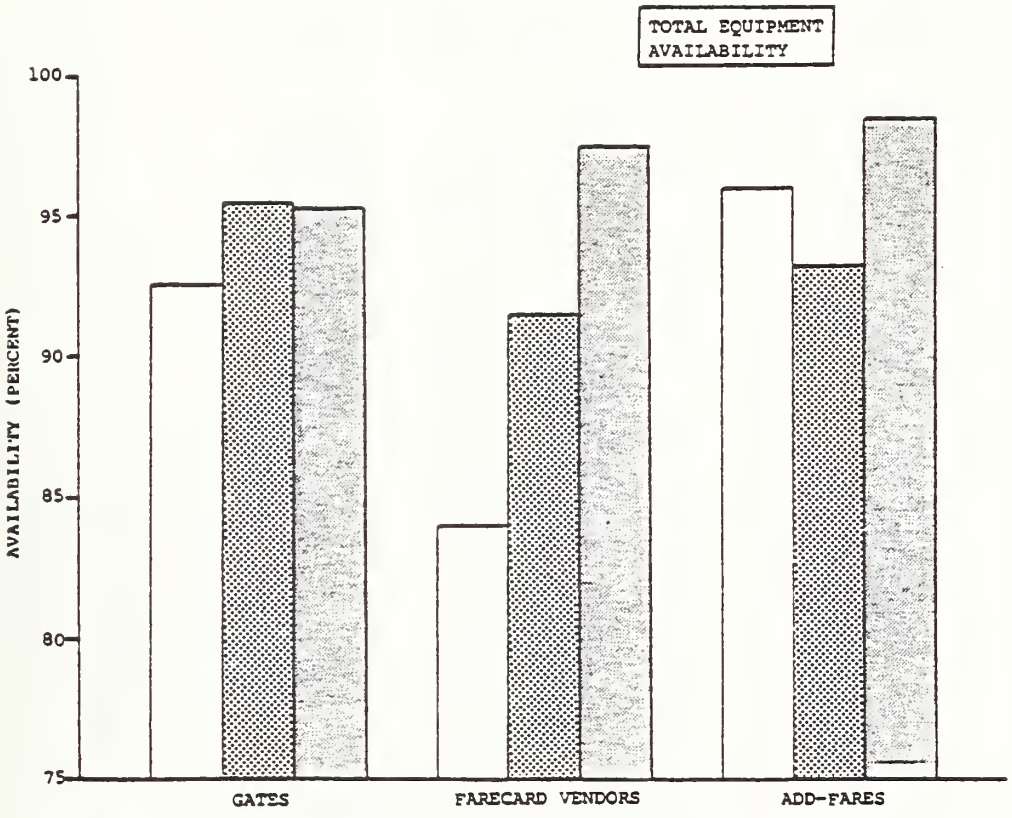


FIGURE 5-2. COMPARISON OF AFC EQUIPMENT AVAILABILITIES: 1978-1979 SURVEY (PRE-RETROFIT) AND 1980 SURVEY (RETROFITS A & B)

PRE-RETROFIT

RETROFIT A

RETROFIT B

TABLE 5-5. COMPARISON OF MEAN TIME BETWEEN PEAK-HOUR FAILURES FOR AFC EQUIPMENT: 1978-1979 SURVEY (PRE-RETROFIT) AND 1980 SURVEY (RETROFITS A AND B) — TOTAL EQUIPMENT MBTF

AFC EQUIPMENT	MEAN TIME[1] BETWEEN FAILURES								
	PRE-RETROFIT	RETROFIT A				RETROFIT B			
		FEBRUARY	MARCH[2]	APRIL	TOTAL	FEBRUARY	MARCH	APRIL	TOTAL
Gates	1.12	1.72	7.58	2.62**	2.19**	3.13	9.10	8.75**	4.17**
Farecard Vendors	1.96	1.49	1.39	2.63**	1.74	3.04	2.17	2.81**	2.79**
Add-fares	1.47	1.41	1.45	2.31**	1.62**	2.23	4.33	7.50**	2.91**

[1]Time in peak hours
[2]Farragut West, 17th Street only
**Significant improvement over 1978-1979 at 99 percent confidence level

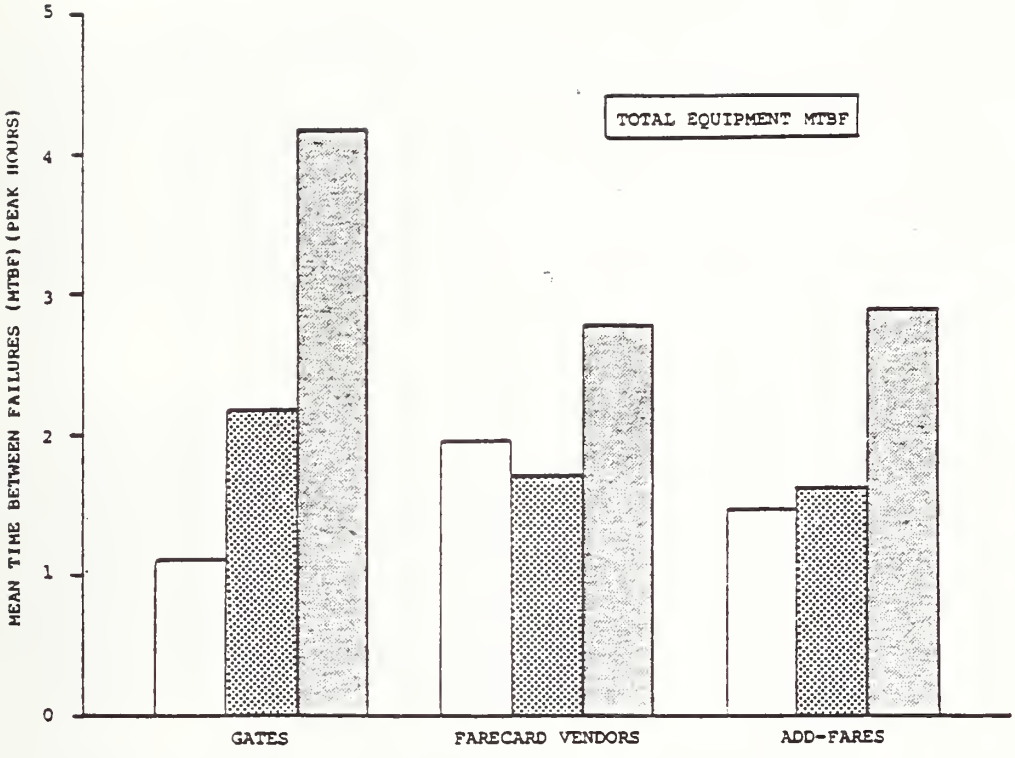


FIGURE 5-3. COMPARISON OF MEAN TIME BETWEEN FAILURES (PEAK HOUR) FOR AFC EQUIPMENT: 1978-1979 SURVEY (PRE-RETROFIT) AND 1980 SURVEY (RETROFITS A & B)

5.2.2 Overall Element Performance

To measure the effectiveness of retrofit element performance, reliability measures were calculated in terms of actual element usage and compared to pre-retrofit performance measures. Tables 5-6 through 5-8 show mean transactions per failure for the elements, and Figures 5-4 through 5-6 show the reliabilities graphically.

Retrofit A produced significant improvements in the reliability of ticket transports for gates and farecard vendors; add-fares showed a marked decrease in reliability. Retrofit B produced significant reliability improvements for gates and farecard vendors, but only marked increase for add-fares. All Retrofit B equipment showed significant improvement over Retrofit A.

No coin acceptors (Retrofit A or B) exhibited any significant improvements in reliability. Retrofit A farecard vendors produced reliabilities better than pre-retrofit and Retrofit B farecard vendors. Add-fare reliabilities were markedly lower than pre-retrofit, but Retrofit B did show an increase over Retrofit A. There was no statistical difference in performance between the retrofits.

Bill verifier reliabilities for Retrofit B increased significantly for farecard vendors and add-fares; Retrofit A produced significant increase only for add-fares. Statistical analysis of Retrofit A and Retrofit B data indicated that there was no difference in the bill verifier performance of either retrofit program.

Overall, significant improvements to the elements were only demonstrated in the ticket transport reliabilities; coin and bill elements did not produce conclusive performance improvements. Statistical analysis indicates that Retrofit B performed better than Retrofit A for the Ticket transport, but there was no difference between the retrofit programs for the coin acceptor or bill verifier.

TABLE 5-6. COMPARISON OF MEAN TRANSACTIONS PER FARECARD JAM FOR AFC EQUIPMENT: 1978-1979 SURVEY (PRE-RETROFIT) AND 1980 SURVEY (RETROFITS A AND B) - TICKET TRANSPORT RELIABILITY

AFC EQUIPMENT	MEAN TRANSACTIONS PER FARECARD JAM								
	PRE RETROFIT	RETROFIT A				RETROFIT B			
		FEBRUARY	MARCH[1]	APRIL	TOTAL	FEBRUARY	MARCH	APRIL	TOTAL
Gates	858	1,381**	20,977/0**	1,034	1,477**	11,399**	8,109**	15,649**	11,274**
Farecard Vendors	376	477	510	885**	573**	6,148**	1,137**	4,965**	3,445**
Add-fares	552	143	79	243	154	833	939	772	872

[1]Farragut West, 17th St. only

**Significant improvement over 1978-1979 at 99 percent confidence level

TABLE 5-7. COMPARISON OF MEAN NUMBER OF COINS INSERTED PER COIN JAM FOR FARECARD VENDORS AND ADD-FARES: 1978-1979 SURVEY (PRE-RETROFIT) AND 1980 SURVEY (RETROFITS A AND B) - COIN ACCEPTOR RELIABILITY

AFC EQUIPMENT	MEAN NUMBER OF COINS INSERTED PER COIN JAM								
		RETROFIT A				RETROFIT B			
	PRE-RETROFIT	FEBRUARY	MARCH[1]	APRIL[1]	TOTAL	FEBRUARY	MARCH	APRIL	TOTAL
Farecard Vendors	844	1,062	734	2,893	1,058	1,125	956	871	1,027
Add-fares	2,115	412	690	924	510	1,082	563	824/0*	1,039

[1]Farragut West, 17th St. only

*Significant improvement on 1978-1979 at the 95 percent confidence level

TABLE 5-8. COMPARISON OF MEAN NUMBER OF BILLS INSERTED ER BILL JAM FOR FARECARD VENDORS AND ADD-FARES: 1978-1979 SURVEY (PRE-RETROFIT) AND 1980 SURVEY (RETROFITS A AND B) - BILL VERIFIER RELIABILITY

	MEAN NUMBER OF BILLS INSERTED PER BILL JAM								
		RETROFIT A				RETROFIT B			
AFC EQUIPMENT	PRE-RETROFIT	FEBRUARY	MARCH[1]	APRIL[1]	TOTAL	FEBRUARY	MARCH	APRIL	TOTAL
Farecard Vendors	358	444	553	299	459	622**	305	971**	572**
Add-fares	40	616**	130/0**	203**	474**	311**	281/0**	432/0**	454**

[1]Farragut West, 17th St. only

**Significant improvement over 1978-1979 at 99 percent confidence level

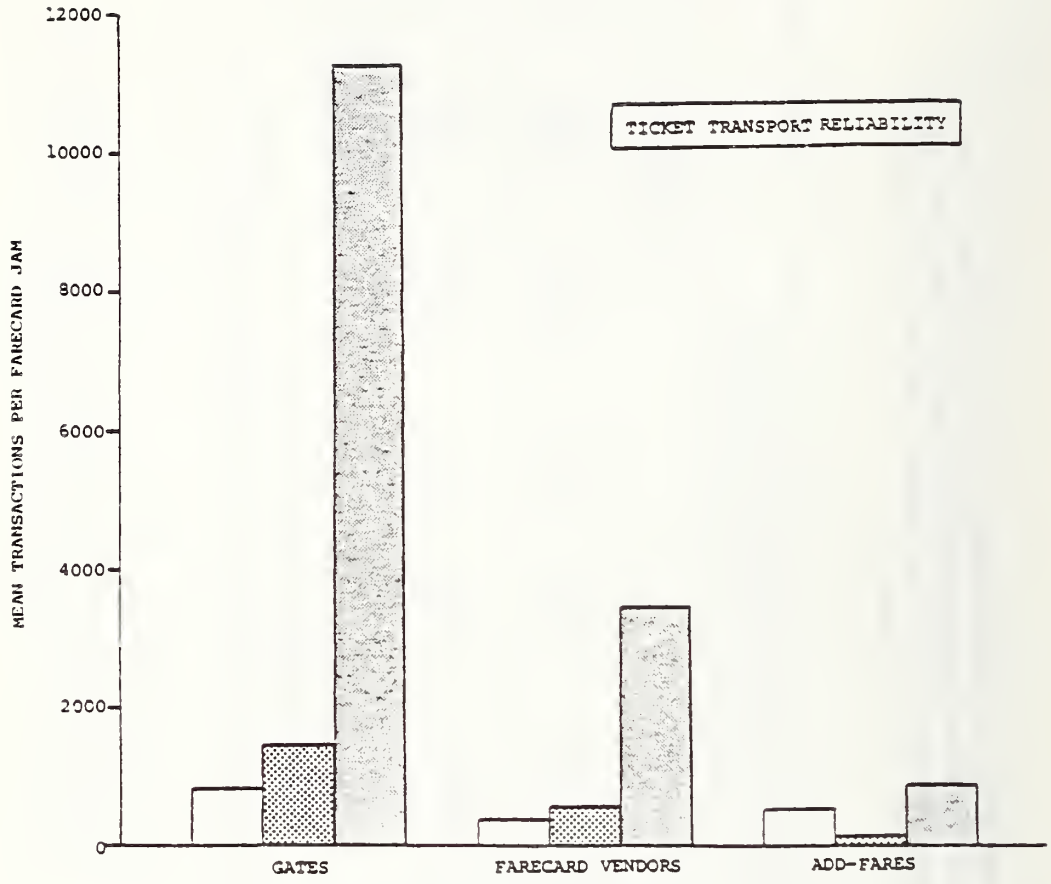


FIGURE 5-4. COMPARISON OF MEAN TRANSACTIONS PER FARECARD JAM FOR AFC EQUIPMENT: 1978-1979 SURVEY (PRE-RETROFIT) AND 1980 SURVEY (RETROFITS A & B)

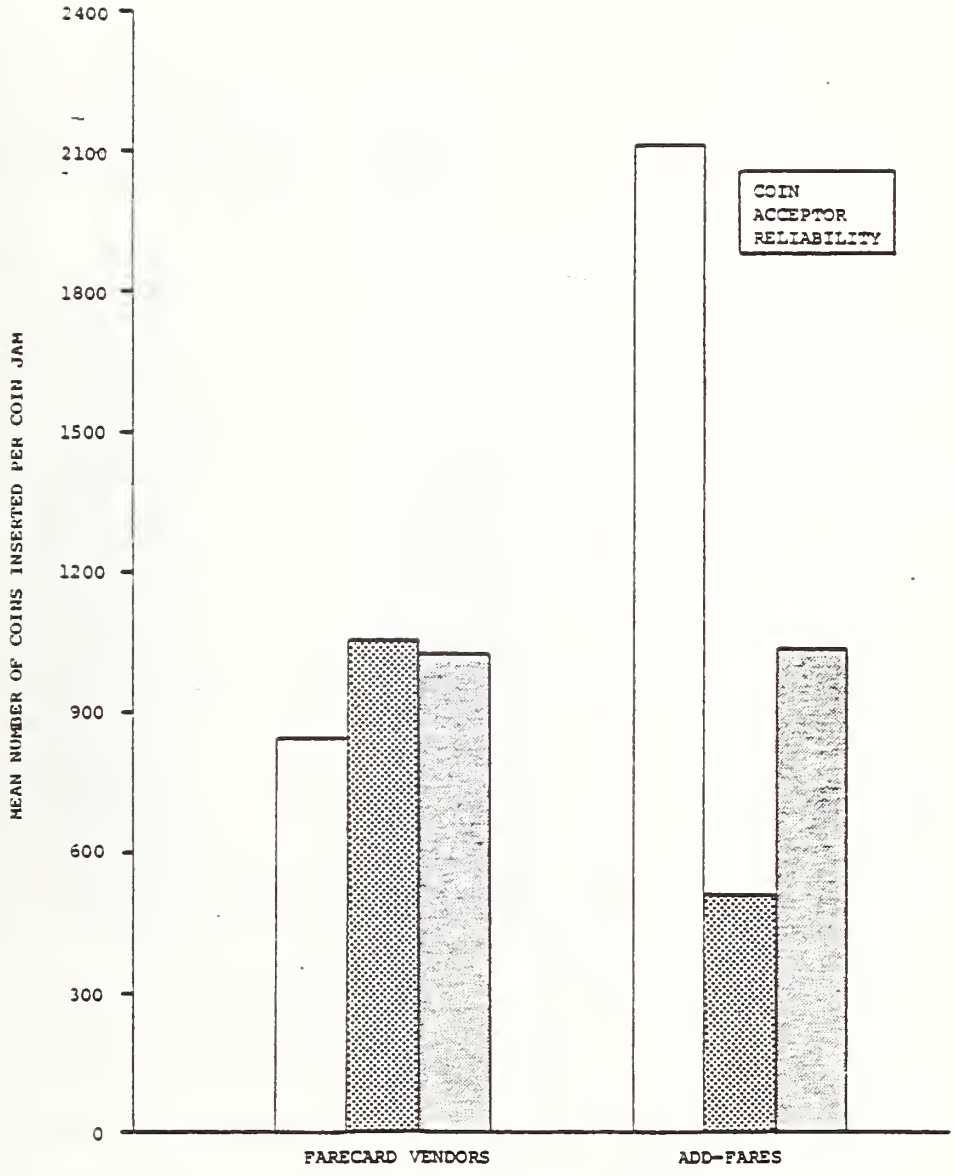


FIGURE 5-5. COMPARISON OF MEAN NUMBER OF COINS INSERTED PER COIN JAM FOR FARECARD VENDORS AND ADD-FARES: 1978-1979 SURVEY (PRE-RETROFIT) AND 1980 SURVEY (RETROFITS A AND B)

PRE-RETROFIT

RETROFIT A

RETROFIT B

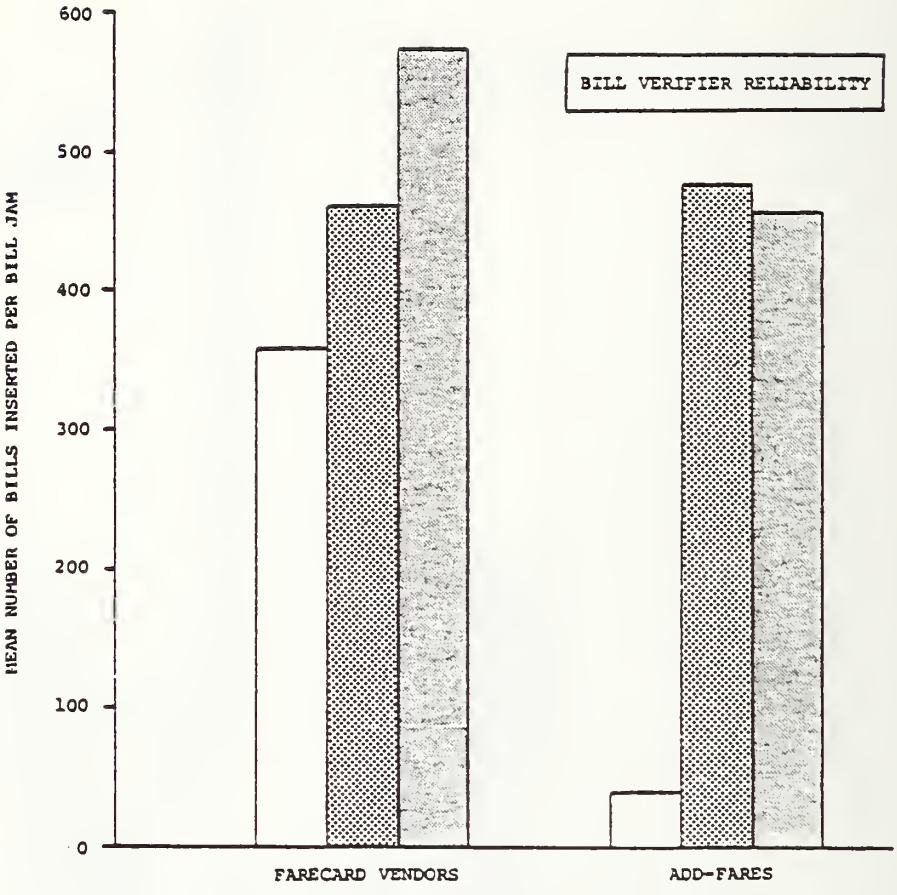


FIGURE 5-6. COMPARISON OF MEAN NUMBER OF BILLS INSERTED PER BILL JAM FOR FARECARD VENDORS AND ADD-FARES: 1978-1979 SURVEY (PRE-RETROFIT) AND 1980 SURVEY (RETROFITS A & B)

PRE-RETROFIT

RETROFIT A

RETROFIT B

Reliability data were collected during off-peak periods and compared to peak period data. Table 5-9 summarizes the results of this comparison and indicates a wide disparity among the data. Therefore, it is not possible to draw conclusions about peak or off-peak performance.

Another alternative for examining element performance is to calculate the distribution of total failures. The pie charts in Figures 5-7 through 5-9 show each type of failure for farecard vendors as a percentage of the total transactions at each mezzanine. The 1978-1979 data are also presented for purposes of comparison.

At Rosslyn (Retrofit A) farecard jams were reduced from 35 percent to 8 percent of the total failures; coin jams increased dramatically, bill jams increased slightly, and hard and other soft failures decreased slightly. At Farragut West, 17th Street (Retrofit A) farecard jams increased to 30 percent of the total failures. Coin jams and soft failures also increased, while bill jams decreased substantially. The effect of Retrofit A on the performance of farecard vendors was not consistent.

Farragut West, 18th Street (Retrofit B) farecard jams decreased substantially to only 8 percent of the failures. Coin and bill jams increased significantly while all other failures (hard and soft) remained the same. The only element that appeared to be effected by Retrofit B was the ticket transport.

5.2.3 Equipment Specific: Overall and Element Performance

All machines at each retrofit mezzanine were examined to identify the magnitude and location of changes in AFC equipment performance including ticket transport, bill verifier and coin acceptor elements. Tables 5-10 through 5-12 show the results for each mezzanine. The tables are divided into two comparisons:

TABLE 5-9. COMPARISON OF PEAK AND OFF-PEAK MEAN TRANSACTIONS PER FAILURE FOR FARRAGUT WEST, 17TH STREET, AND FARRAGUT WEST, 18TH STREET, 1980: AFC EQUIPMENT AND ELEMENTS

	MEAN TRANSACTIONS PER FAILURE			
	FARRAGUT WEST 17TH ST. (A)		FARRAGUT WEST 18TH ST. (B)	
AFC EQUIPMENT	PEAK	OFF-PEAK	PEAK	OFF-PEAK
Gates				
Farecard Jams	1,392	4,743	11,399	6,597
Total Failures	553	1,186	1,596	347
Farecard Vendors				
Farecard Jams	298	284	6,148	1,365/0
Coin Jams	1,343	1,348/0	1,125	1,711
Bill Jams	440	257	622	1,035/0
Total Failures	94	81	279	1,365
Add-Fares				
Farecard Jams	108	141/0	883	240/0
Coin Jams	428	195/0	1,082	319
Bill Jams	338	34/0	311	49/0
Total Failures	54	0	132	48

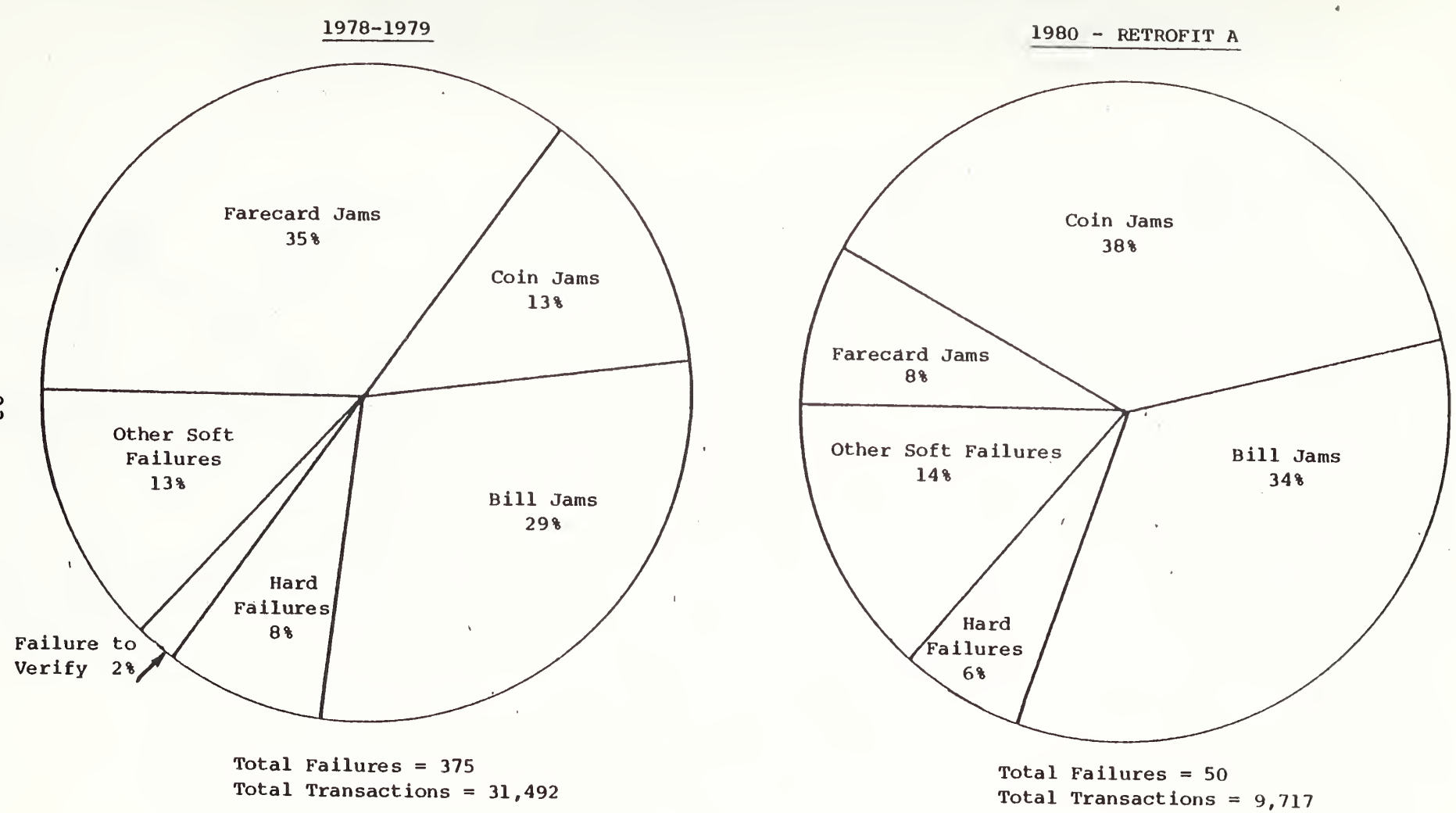


FIGURE 5-7. FARECARD VENDOR FAILURE DISTRIBUTION: ROSSLYN, 1978-1979 SURVEY (PRE-RETROFIT) AND 1980 SURVEY (RETROFIT A)

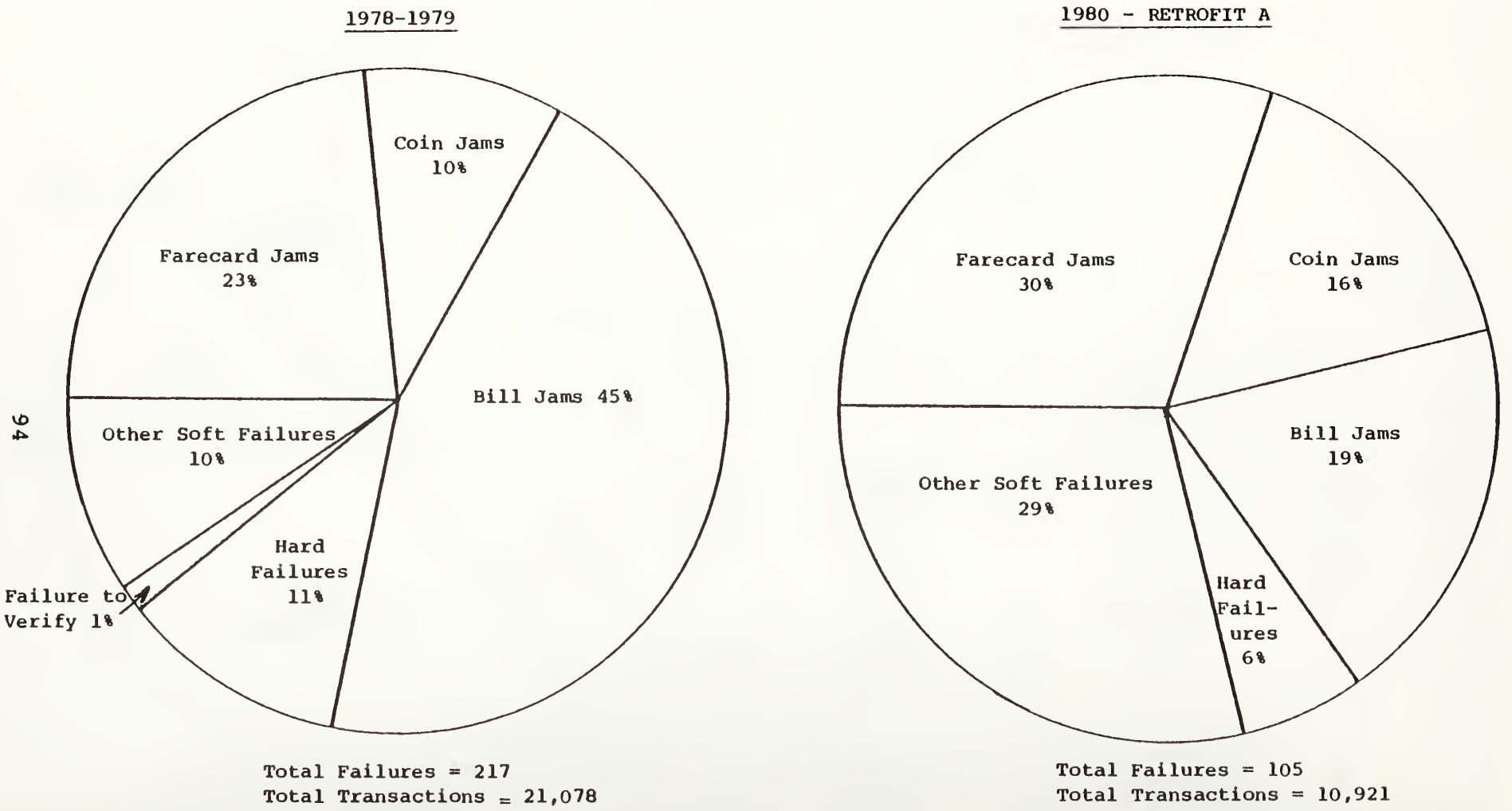


FIGURE 5-8. FARECARD VENDOR FAILURE DISTRIBUTION: FARRAGUT WEST 17th STREET, 1978-1979 SURVEY (PRE-RETROFIT) AND 1980 SURVEY (RETROFIT A)

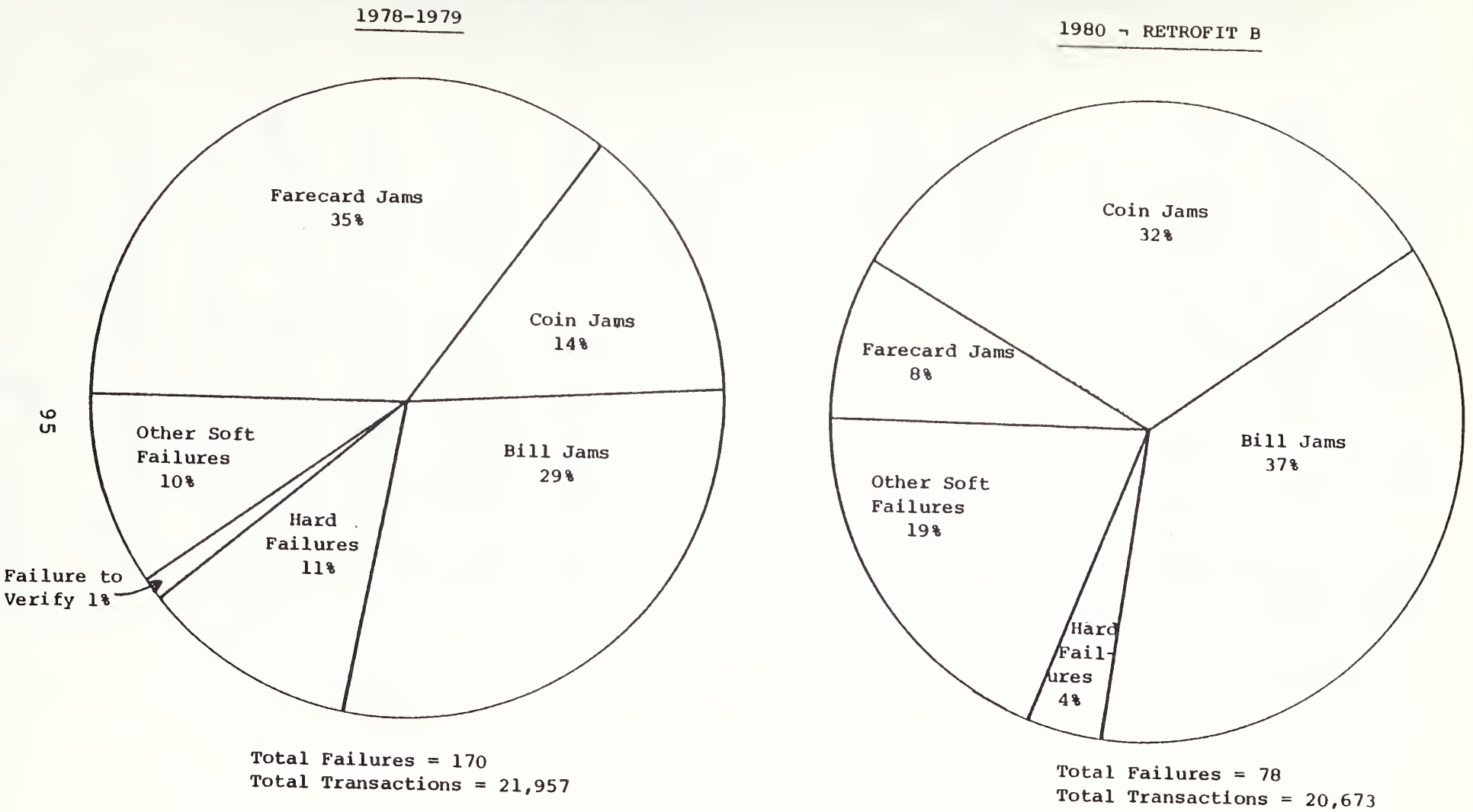


FIGURE 5-9. FARECARD VENDOR FAILURE DISTRIBUTION: FARRAGUT WEST, 18th STREET, 1978-1979 SURVEY (PRE-RETROFIT) AND 1980 SURVEY (RETROFIT B)

TABLE 5-10. DETAILED AFC EQUIPMENT RELIABILITIES:[1] ROSSLYN, RETROFIT A, 1978-1979 AND FEBRUARY AND APRIL, 1980

AFC Equipment	Mean Transactions Per Farecard Jam			Mean Number of Coins Inserted Per Coin Jam			Mean Number of Bills Inserted Per Bill Jam			Mean Transactions Per Failure		
	Pre-Retrofit	February Post-Retrofit	April Post-Retrofit	Pre-Retrofit	February Post-Retrofit	April[2] Post-Retrofit	Pre-Retrofit	February Post-Retrofit	April[2] Post-Retrofit	Pre-Retrofit	February Post-Retrofit	April Post-Retrofit
Gates												
10	4,372	1,470/0	747							2,186	1,470/0	373
11	1,972	2,582	927							1,479	861	927
12	580	991	1,647							515	248	1,647
13	1,742	1,039	136							697	520	136
14	4,693	819	968							1,173	819	968
15	200	86	405							170	86	405
18	2,035	3,474	2,664							1,526	217	2,664
19	696	2,141/0	2,282							440	1,071	1,141
20	1,455	744	3,058/0							970	372	3,058/0
21	459	5,437	238							408	5,437	220
22	2,260	1,259	2,493							1,291	472	1,246
Average	940	1,365	772							656	491	664
Vendors												
31	N/A	N/A	1,108/0	N/A	N/A		N/A	N/A		N/A	N/A	277
32	227	1,203/0	1,017/0	2,269	1,043		231	837		103	241	203
33	313	966	1,193/0	1,237	922/0		223	640		116	322	1,193/0
34	476	1,074/0	40/0	1,427	615		1,164	244		109	153	13
38	714	529	478/0	1,179	461		249	344		167	76	80
39	114	530	455	1,457	1,378		147	332		51	88	455
40	400	268	313/0	1,665	675		551	379/0		154	178	313/0
41	N/A	N/A	276/0	N/A	N/A		N/A	N/A		N/A	N/A	276/0
Average	350	1,612	4,878	1,228	829		296	450		134	156	257
Mid-Fares												
50	254	521	177	1,316/0	673		27	128		53	174	89
51	1,289	147	576/0	1,334	814		96	150/0		215	84	576/0
Average	461	222	465	2,650	744		46	278		92	111	233

[1]March data not available
[2]DADS printer control board out of service; no coin or bill counts
N/A: Not available

TABLE 5-11. DETAILED AFC EQUIPMENT RELIABILITIES: FAREMART WEST 17th STREET, RETROFIT A, 1978-1979 AND FEBRUARY, MARCH AND APRIL 1980

AFC Equipment	Mean Transactions Per Farecard Jam				Mean Number of Coins Inserted Per Coin Jam				Mean Number of Bills Inserted Per Bill Jam				Mean Transactions Per Failure[1]			
	Pre-Retrofit	February Post-Retrofit	March Post-Retrofit	April Post-Retrofit	Pre-Retrofit	February Post-Retrofit	March Post-Retrofit	April Post-Retrofit	Pre-Retrofit	February Post-Retrofit	March Post-Retrofit	April Post-Retrofit	Pre-Retrofit	February Post-Retrofit	March Post-Retrofit	April Post-Retrofit
Gates																
10	927	465	2,682/0	2,952/0									464	220	1,341	2,952/0
11	519	691	4,246/0	2,407/0									346	346	4,246/0	2,407
12	661	4,567	1,340/0	2,160									578	351	1,340	2,160
13	384	5,119	1,944/0	503									247	1,024	1,944/0	335
14	460	785	1,366/0	1,386									532	561	1,366	1,386
15	582	3,572	6,069/0	733/0									466	2,381	6,069	367
16	509	5,028	3,330/0	3,086									382	2,514	3,330	3,086
Average	604	1,392	20,977/0	2,015									421	553	3,496	1,240
Vendors																
30	526	350	145	379	2,241	1,443	378	480/0	225	562	108	294	131	100	32	126
31	417	147	415/0	97	1,369	519	614	444/0	199	233	343/0	329	81	53	104	73
32	294	744	455/0	317	2,302	1,888/0	652	482/0	104	544	297/0	206/0	65	124	228	317
33	244	1,143/0	538/0	447	462	458	906	539/0	135	225	426/0	175	70	76	538	112
34	1,250	395	606/0	432	875	2,800/0	402	584	195	871/0	411	319	109	198	152	144
35	667	143	190	336/0	1,425	3,511	1,019/0	364/0	159	822	521	295	83	96	95	168
Average	430	298	510	367	1,129	1,343	734	2,893	161	440	553	299	97	94	109	130
Mid-Fares																
50	310	61	56	91	201	311	296	454	58	97/0	40/0	76	70	23	37	61
51	286	147	125	406	342/0	546/0	394/0	470/0	36	247/0	82/0	127/0	57	98	83	203
Average	298	108	79	154	372	428	690	924	43	338/0	130/0	203	66	54	53	96

[1]Failure = all failures, hard and soft.

TABLE 5-12. DETAILED AFC EQUIPMENT RELIABILITIES: FARRAGUT WEST 10th STREET, DETROIT D, 1978-1979 AND FEBRUARY, MARCH AND APRIL 1980

AFC Equipment	Mean Transactions Per Farecard Jam				Mean Number of Coins Inserted Per Coin Jam				Mean Number of Bills Inserted Per Bill Jam				Mean Transactions Per Failure[1]			
	Pre-Retrofit	February Post-Retrofit	March Post-Retrofit	April Post-Retrofit	Pre-Retrofit	February Post-Retrofit	March Post-Retrofit	April Post-Retrofit	Pre-Retrofit	February Post-Retrofit	March Post-Retrofit	April Post-Retrofit	Pre-Retrofit	February Post-Retrofit	March Post-Retrofit	April Post-Retrofit
Gates																
10	689	4,964	4,005/0	5,810/0									689	1,354	4,005/0	5,817
11	1,239	15,403	4,195/0	5,970/0									929	1,711	4,195/0	5,970/0
12	921	7,476/0	2,785/0	1,803									837	7,476	2,785/0	1,255
13	513	8,316/0	3,503	2,170/0									513	8,316/0	1,194	2,170
18	4,503	5,642	2,328/0	3,915/0									2,292	2,257	2,328/0	3,914
19	1,672	16,448/0	4,462/0	6,570/0									1,254	16,448	4,462/0	6,570/0
20	1,230	2,987	1,485	3,082/0									1,230	260	1,485	3,082/0
Average	950	11,399	8,109	15,649									864	1,596	4,865	5,216
Wenbus																
30	204	2,161/0	4,076	802/0	1,667	1,310	513	955/0	769	782	464/0	650/0	108	270	487	802/0
31	625	2,403/0	221	760	5,000	760	491	498	1,250	385	103	590	323	218	49	110
32	270	2,500/0	630/0	774/0	1,250	3,201	644	925	230	601	250	213	96	500	210	155
33	313	1,370/0	639/0	884/0	417	867	740	1,115/0	152	1,070	500/0	689/0	69	343	639	884/0
34	769	1,247/0	560/0	839/0	1,429	1,503/0	589/0	993	182	960/0	205	624/0	127	1,247/0	284	839
35	556	1,308	644	900/0	1,429	715	849/0	370	286	482	447	691/0	179	163	322	300
Average	372	6,148	1,137	4,965	1,278	1,125	957	871	312	622	305	971	129	279	189	310
Mid-Farem																
50	771	603	470/0	426	1,031/0	1,700	571/0	437/0	26	473	148/0	207/0	96	137	470/0	426
51	771/0	1,203	469	346/0	1,004/0	274	270	387/0	52	204	133/0	225/0	185	120	156	346
Average	1,542	803	939	772	2,035/0	1,082	563	824/0	34	311	281/0	432/0	126	132	313	386

[1]Failure = all failures, hard and soft.

pre-retrofit versus monthly post-retrofit (February, March and April 1980). The following equipment specific observations are made for each mezzanine:

1. Retrofit A

Rosslyn:

gates - six out of eleven gates had increases for ticket transport and total reliability.

farecard vendors - all farecard vendors had increases in ticket transport reliability, and four had increases in total reliability. Coin acceptor and bill verifier reliability could not be assessed due to a malfunction of the DADS printer control board.

add-fares - one of the two add-fares had an increase in total reliability.

Farragut West, 17th Street:

gates - all gates demonstrated increased ticket transport reliability; total reliability increased for all gates but was somewhat inconsistent in April.

farecard vendors - ticket transport reliability showed consistent increases in only two machines; five machines demonstrated consistent improvements for the coin acceptor with only one machine encountering a failure in April; the bill verifier produced reliability increases; only four machines demonstrated consistent improvements in total reliability.

add-fares - the only consistent improvements occurred in coin acceptor reliability; one machine demonstrated improvements in total reliability.

2. Retrofit B

Farragut West, 18th Street:

gates - all gates demonstrated consistent ticket transport and total reliability improvements, with six gates showing no farecard jams in April.

farecard vendors - all six farecard vendors had increased ticket transport reliability over the three-month period. These farecard vendors exhibited decreases in coin acceptor reliability and inconsistency with the remaining machines. Bill verifier reliability decreased for two machines, but demonstrated consistent increases for four other farecard vendors. Total reliability increased for five machines, but one machine showed a consistent decrease in total reliability.

add-fares - increase in bill verifier and total reliability was demonstrated by both add-fares; ticket transport and coin acceptor reliabilities were consistent with pre-retrofit data.

Table 5-13 shows availability measures for each mezzanine. Tables 5-14 through 5-16 show MTBF for all equipment by mezzanine. Most AFC equipment was achieving 95 percent availability at all mezzanines except for the farecard vendors at Farragut West, 17th Street, which show reduced availabilities for April 1980. One gate at Farragut West, 18th Street demonstrated an availability of only 53 percent due to a broken part which had to be ordered. Overall, availabilities appear to

TABLE 5-13. DETAILED AFC EQUIPMENT AVAILABILITY[1] FOR 1980 SURVEY (RETROFITS A AND B)

AFC Equipment	Rosslyn[2] (Retrofit A) Machine #	February	April	Farragut W. 17th Street (Retrofit A) Machine #	February	March	April	Farragut W. 18th Street (Retrofit B) Machine #	February	March	April
Gates:	10	100.00	95.21	10	83.79	84.87	100.00	10	98.25	100.00	99.56
	11	99.45	99.68	11	98.52	100.00	99.72	11	89.81	100.00	100.00
	12	81.61	99.36	12	95.87	85.64	97.78	12	100.00	100.00	99.00
	13	99.54	98.19	13	99.45	100.00	99.03	13	82.84	99.49	53.33[3]
	14	99.91	99.89	14	99.14	99.49	99.03	18	98.92	100.00	99.89
	15	99.17	99.79	15	94.33	87.18	88.89	19	99.85	100.00	100.00
	18	95.38	99.89	16	90.95	89.74	99.86	20	94.78	99.62	100.00
	19	96.12	96.60								
	20	76.06	100.00								
	21	99.91	83.83								
	22	96.77	90.85								
Average		94.90	96.66		95.72	92.42	97.76		94.92	94.87	93.11
Farecard	31	N/A	98.40								
Vendors	32	99.45	93.83	30	72.75	86.41	96.81	30	98.69	98.97	100.00
	33	94.18	100.00	31	73.18	87.82	89.72	31	94.22	86.54	96.22
	34	96.95	91.25	32	84.09	97.31	98.61	32	94.22	97.05	93.11
	38	98.43	95.96	33	87.55	95.90	86.67	33	98.57	99.74	100.00
	39	96.03	98.09	34	96.92	95.13	99.44	34	100.00	97.44	99.33
	40	99.26	100.00	35	88.16	89.87	70.56	35	96.57	98.21	99.44
	41	N/A	100.00								
Average		97.38	97.58		83.78	92.07	90.30		97.51	96.32	98.02
Mid-Fares	50	99.44	92.87	50	72.87	88.85	92.64	50	99.01	100.00	99.89
	51	98.81	100.00	51	99.32	99.49	99.31	51	99.07	98.97	99.56
Average		99.12	96.44		86.10	94.17	95.97		98.08	99.49	99.72

[1] Availability = $\frac{\text{Total Operating Time - Total Down Time}}{\text{Total Operating Time}}$

[2] March data not available.

[3] Machine placed out of service; part had to be ordered.

TABLE 5-14. COMPARISON OF MTBF FOR AFC EQUIPMENT AT ROSSLYN: 1978-1979 SURVEY (PRE-RETROFIT) AND 1980 SURVEY (RETROFIT A)

		MEAN TIME BETWEEN FAILURES (MTBF)[1]		
		PRE-RETROFIT	RETROFIT A FEBRUARY	APRIL
Gates:	10	6.38	No Failures	1.96
	11	3.19	3.01	3.92
	12	1.42	2.25	7.83
	13	1.28	4.51	1.12
	14	3.19	9.02	7.83
	15	0.64	1.29	7.83
	18	3.19	0.56	7.83
	19	0.67	3.46	3.92
	20	1.42	1.50	No Failures
	21	0.71	9.02	0.60
	22	1.82	1.13	1.96
Vendors:	31	N/A	N/A	1.96
	32	1.19	1.80	1.57
	33	1.59	3.01	No Failures
	34	1.92	1.29	1.33
	38	2.41	1.29	1.31
	39	2.58	1.50	7.83
	40	2.88	3.01	No Failures
	41	N/A	N/A	No Failures
Add-Fares:	50	0.67	3.01	1.96
	51	2.13	1.29	No Failures

[1]Time in Peak-Hours
N/A = No Data Available

TABLE 5-15. COMPARISON OF MTBF FOR AFC EQUIPMENT AT FARRAGUT WEST 17TH STREET: 1978-1979 SURVEY (PRE-RETROFIT) AND 1980 SURVEY (RETROFIT A)

		MEAN TIME BETWEEN FAILURES (MTBF)[1]			
			RETROFIT A		
		PRE-RETROFIT	FEBRUARY	MARCH	APRIL
Gates:	10	1.60	0.71	3.24	No Failures
	11	2.13	0.97	No Failures	6.00
	12	1.60	1.04	6.50	6.00
	13	0.91	2.70	No Failures	1.00
	14	1.28	1.93	6.50	3.00
	15	1.28	4.51	6.50	3.00
	16	3.19	6.76	6.50	6.00
Vendors:	30	1.91	1.93	0.72	2.00
	31	1.74	0.97	1.63	1.50
	32	1.15	2.25	3.25	6.00
	33	1.19	0.90	6.50	1.50
	34	1.91	2.25	1.63	2.00
	35	2.20	1.13	0.81	3.00
Add Fares:	50	2.07	1.04	1.08	1.00
	51	1.65	1.50	2.17	3.00

[1]Time in peak hours

TABLE 5-16. COMPARISON OF MTBF FOR AFC EQUIPMENT AT FARRAGUT WEST 18TH STREET: 1978-1979 SURVEY (PRE-RETROFIT) AND 1980 SURVEY (RETROFIT B)

		MEAN TIME BETWEEN FAILURES (MTBF)[1]			
			RETROFIT B		
		PRE-RETROFIT	FEBRUARY	MARCH	APRIL
Gates:	10	0.98	2.03	No Failures	7.50
	11	1.60	2.48	No Failures	No Failures
	12	1.16	No Failures	2.17	2.50
	18	6.38	4.47	No Failures	7.50
	19	3.19	22.33	No Failures	No Failures
	20	2.55	0.97	3.25	No Failures
Vendors:	30	1.75	2.79	6.50	No Failures
	31	4.00	2.03	0.72	1.07
	32	1.55	4.47	2.17	1.50
	33	1.38	5.58	6.50	No Failures
	34	2.24	No Failures	3.25	7.50
	35	2.15	1.40	3.25	2.50
Add-Fares	50	1.60	2.23	No Failures	7.50
	51	3.19	2.23	2.17	7.50

[1]Time in peak hours

be increasing due to the retrofit programs and greater familiarity with corrective action procedures, but greater consistencies in availability are still required for improved performance.

Mean time between failures (MTBF) appears to show increases at all mezzanines. While the increases are not at a consistent rate, many of them are quite substantial over the pre-retrofit condition.

5.3 SUMMARY

The findings of the 1980 retrofit performance analysis may be summarized as follows:

1. Overall Equipment Performance

   Retrofit A - Significant improvements occurred in gate reliabilities; farecard vendors experienced some improvements while add-fares showed a slight decrease in reliability. The availabilities of gates and farecard vendors were significantly improved although only gates achieved 95 percent availability. Add-fares demonstrated a decrease over the pre-retrofit availability. Mean time between failures increased significantly for gates and add-fares but decreased slightly for farecard vendors.

   Retrofit B - Significant improvements occurred in the reliabilities and availabilities of gates, farecard vendors and add-fares. Gates achieved a reliability of 2,220 transactions per failure which was a fourfold increase in the pre-retrofit condition. All equipment achieved an availability over 95 percent and showed a significant increase in mean time between failures.

2. Overall Element Performance

Retrofit A - Gates and farecard vendors showed a significant increase in ticket transport reliability. There were no significant improvements in coin acceptor reliability, but the bill verifier did demonstrate a significant improvement for add-fares.

Retrofit B - Gates and farecard vendors demonstrated significant improvements in ticket transport reliability. Add-fares also had a marked increase in ticket transport reliability.

No significant improvements were found for the coin acceptor and add-fares did not perform as well as the pre-retrofit equipment. The bill verifier demonstrated a significant improvement for add-fares and farecard vendors.

3. Equipment Specific: Overall and Element Performance

Retrofit A

Rosslyn - All farecard vendors and half of the gates experienced improvements in ticket transport reliability; all other AFC equipment showed inconsistent performance. With the exception of a few machines, most of the AFC equipment met 95 percent availability.

Farragut West, 17th Street - All gates had significant improvements in ticket transport reliabilities; farecard vendors showed minor improvements. An availability of 95 percent was not met by a large portion of the equipment; farecard vendors were particularly inconsistent in this performance area.

Retrofit B

Farragut West, 18th Street - All gates and farecard vendors had increased ticket transport reliabilities, and all AFC equipment experienced an increase in total reliability. There were no significant or consistent improvements in the coin acceptors; bill verifiers showed marked improvements. With the exception of one gate and one farecard vendor, all AFC equipment achieved 95 percent availability.

6. SYSTEM IMPACT ANALYSIS

Reliability and availability measures have been utilized in this report to estimate AFC equipment performance, and to determine if changes to equipment elements have improved AFC equipment performance. Another useful application of reliability measures is to combine them with passenger flow distributions to provide an estimate of system reliability. Alternative system reliabilities can then be compared, and the impact of improvements to some or all of the AFC equipment can be quantified on a system-wide basis. This chapter examines and compares the impact of the following fare collection alternatives on system failures and maintainability:

1. Improved ticket transport, coin acceptor and bill validator (Retrofit B);

2. $1 and $5 fast vendors;

3. One- or two-ride fast vendors; and

4. Current AFC system operating under optimum performance (at least 10,000 transactions per failure and 95 percent availability).

6.1 System Failure and Average Down-Time Estimation

Another study* has developed methods for estimating the expected failures per 1,000 passengers and the probability of a passenger encountering a delay. The latter system measure utilized the group availability, or the probability that less than two of a certain type of machine would be simultaneously

*JPL, "Fare Collection Alternatives," Draft Interim Report, Contract NAS-7100, DOT AT-80015, January 1980.

out of service. Delay in this particular model was not quantified, and the group availability assumed a specified equipment quantity at each station. Another method for estimating system failures is to combine the reliabilities of AFC equipment with passenger flow distributions. This method estimates the probability that a passenger will encounter a failure somewhere in the AFC system.

Passenger flow distributions were determined by a survey conducted by WMATA. Figure 6-1 shows passenger flows through a typical WMATA mezzanine. For passengers to successfully enter and exit the system four alternatives are available, two each for entry and exit:

Entry

a = passenger enters system, utilizes a farecard vendor to purchase a farecard, and then proceeds to the entry gate.

b = passenger enters the system, already possesses a farecard and goes directly to the entry gate.

Exit

c = passenger attempts to exit through an exit gate, does not have enough remaining stored value on the farecard, and must utilize an add-fare vendor and then return to the exit gate.

d = passenger exits through an exit gate

Passengers may enter and exit a system utilizing any combination of the above-mentioned alternatives.

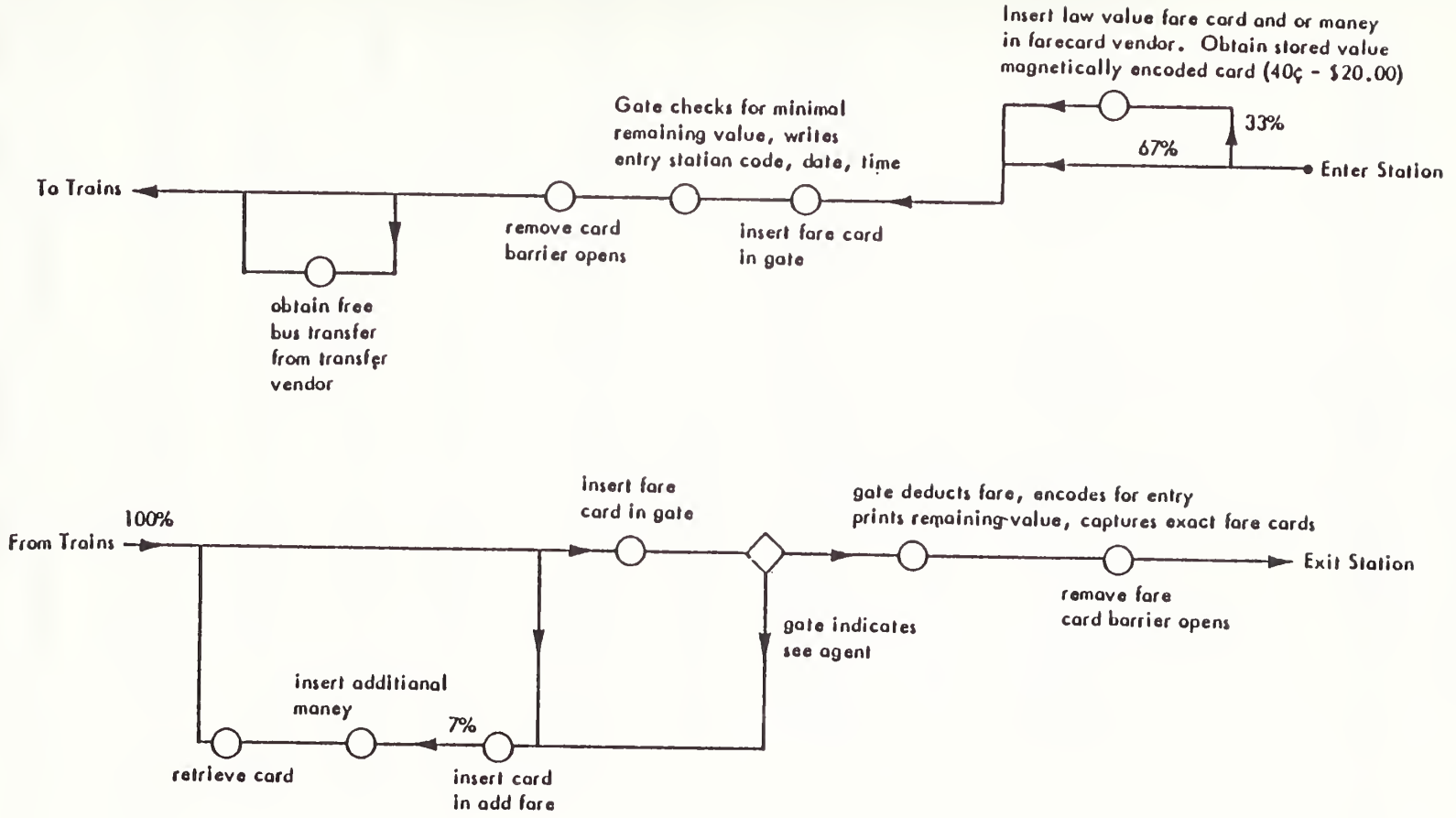


FIGURE 6-1. PASSENGER FLOW DISTRIBUTION - WMATA*

*JPL, "Fare Collection Alternatives," Draft Interim Report, Contract NAS-7100, DOT AT-80015, January 1980.

To estimate the probability of a passenger encountering a failure, the following formula was used:

$$P\ (\text{failure}) = \frac{P(a)W_a + P(b)W_b + P(c)W_c + P(d)W_d}{W_a + W_b + W_c + W_d} \quad (1)$$

where:

P = probability

P(a) = [P(farecard vendor failure)][P(entry gate failure)] +
[P(farecard vendor failure)][P(entry gate success)] +
[P(farecard vendor success)][P(entry gate failure)]

P(b) = P(entry gate failure)

P(c) = [P(exit gate failure)][P(add-fare failure)] +
[P(exit gate failure)][P(add-fare success)] +
[P(exit gate success)][P(add-fare failure)]

P(d) = P(exit gate failure)

W_a = percent of patrons using farecard vendors and entry gates (0.33)

W_b = percent of patrons using entry gates only (0.67)

W_c = percent of patrons using exit gates and add-fares (0.07)

W_d = percent of patrons using exit gates only (1.00)

This formula produces an estimate of the probability of encountering a failure system-wide.

To estimate the probability of encountering a failure at a baseline or existing system configuration station, the data in

Table 6-1 were utilized. Farragut West, 18th St. was utilized as a test station throughout this chapter because it received Retrofit B, and the system impact of this Retrofit could be tested (improvements to the ticket transport, coin acceptor and bill verifier).

TABLE 6-1. RELIABILITIES FOR AFC EQUIPMENT AT FARRAGUT WEST, 18TH STREET, 1978-1979

EQUIPMENT	RELIABILITY	UNRELIABILITY
Entry Gates	0.9995	0.0005
Farecard Vendors	0.9923	0.0077
Exit Gates	0.9983	0.0017
Add-Fares	0.9921	0.0079

Applying the formula to the data results in:

$$P(a) = [(0.0077)(0.0005) + (0.0077)(0.9995) + (0.9923)(0.0005)]$$
$$P(a) = 0.0082$$

$$P(b) = 0.0005$$

$$P(c) = [(0.0017)(0.0079) + (0.0017)(0.9921) + (0.9983)(0.0079)]$$
$$P(c) = 0.0096$$

$$P(d) = 0.0017$$

$W_a = 0.33$

$W_b = 0.67$

$W_c = 0.07$

$W_d = 1.00$

$$P(f) = \frac{(0.0082)(0.33) + (0.0005)(0.67) + (0.0096)(0.07) + (0.0017)(1.00)}{0.33 + 0.67 + 0.07 + 1.00}$$

$P(f) = 0.0026$, or system reliability = 0.9974,

or 26 passengers in 10,000 will experience some type of AFC equipment failure. The formula was also applied to data in which the average reliabilities of all gates, vendors and add-fares had been weighted by the number of transactions. The weighted average reliabilities were then utilized to calculate the probability of a system failure, and the result was 0.0029, or a system reliability of 0.9971.

To calculate the average down time per failure system-wide, (measure of maintainability) a similar prediction method was utilized. For each type of AFC equipment, the number of hard and soft failures and the average down time per failure were calculated. An average down time (ADT) per failure was determined for each type of AFC equipment by weighting the ADT of hard and soft failures by the ratio of soft to hard failures. Table 6-2 summarizes this data for Farragut West, 18th St., 1978-1979.

TABLE 6-2. RATIO OF SOFT TO HARD FAILURES AND AVERAGE DOWN TIME PER FAILURE, FARRAGUT WEST, 18TH STREET, 1978-1979

EQUIPMENT	SOFT FAILURES		HARD FAILURES		ADT* WEIGHTED AVERAGE ALL FAILURES
	NUMBER	ADT*	NUMBER	ADT*	
Gates	54	1.3	1	118	3.42
Vendors	153	8.2	17	116.5	19.03
Add-Fares	12	4.8*	0**	N/A	4.8

*ADT in Peak-Hour Minutes

**No Hard Failures Occurred During Sample Period, January and February, 1979.

The average down time per system failure was calculated as follows:

$$ADT = \frac{(ADT_a)(W_a) + (ADT_b)(W_b) + (ADT_c)(W_c) + (ADT_d)(W_d)}{W_a + W_b + W_c + W_d} \quad (2)$$

where:

W_a, W_b, W_c, W_d, = percent of patrons using combinations of different AFC equipment

ADT_a - ATD_d = average down time per failure for combinations of different AFC equipment

a = farecard vendor, entry gates

b = entry gates

c = exit gates, add-fared, exit gates

d = exit gates

$$ADT = \frac{(3.42 + 19.03)(0.33) + (3.42)(0.67)}{0.33 + 0.67 + 0.07 + 1.00}$$

$$+ \frac{(3.42 + 4.8 + 3.42)(0.07) + (3.42)(1.00)}{0.33 + 0.67 + 0.07 + 1.00}$$

$$ADT = \frac{7.41 + 2.29 + 0.81 + 3.42}{2.07}$$

ADT = 6.73 minutes

The average down time per failure, given the distribution of hard and soft failures and the usage rate of each group of machines is 6.73 minutes. To calculate the average delay to passengers encountering failures requires a complex model containing information on passenger flows, equipment quantities, and queues at the AFC equipment. This type of system model is outside the scope of this study.

6.2 IMPACT OF IMPROVED TICKET TRANSPORT, COIN ACCEPTOR AND BILL VALIDATOR (RETROFIT B)

To determine if a reduction in the number of passengers experiencing failures would occur due to improvements in the AFC equipment, 1980 post-retrofit data were utilized to calculate the probability of a system failure (equation (1)). The data for these calculations are contained in Table 6-3.

Applying the data to the formula results in:

$$P(f) = \frac{(0.0042)(0.33) + (0.0004)(0.67) + (0.0061)(0.07)}{0.33 + 0.67 + 0.07 + 1.00}$$

$$+ \frac{(0.0004)(1.00)}{0.33 + 0.67 + 0.07 + 1.00}$$

P(f) = 0.0012, or system reliability = 0.9988

TABLE 6-3. RELIBAILITY AND ADT FOR ALL FAILURES, FARRAGUT WEST, 18TH STREET, 1980

AFC EQUIPMENT	RELIABILITY	UNRELIABILITY	ADT IN MINUTES ALL FAILURES
Entry Gates	0.9996	0.0004	11.43
Farecard Vendors	0.9962	0.0038	4.01
Exit Gates	0.9996	0.0004	11.43
Add-Fares	0.9943	0.0057	2.32

The results of the system reliability calculation show that 12 passengers out of 10,000 will experience some type of AFC equipment failure. By utilizing the 1980 data for failure down times, the average down time per system failure was calculated as follows:

$$ADT = \frac{(11.43 + 4.01)(0.33) + (11.43)(0.67)}{0.33 + 0.67 + 0.07 + 1.00}$$

$$+ \frac{(11.43 + 2.32 + 11.43)(0.07) + (11.43)(1.00)}{0.33 + 0.67 + 0.07 + 1.00}$$

$$ADT = 12.53$$

The average down time (12.53 minutes) per system failure is greater with the retrofit equipment than without, but the system reliability has improved from 0.9971 to 0.9988.

6.3 IMPACT OF $1 AND $5 FAST VENDORS

One alternative considered for the WMATA AFC system was the implementation of $1 and $5 fast vendors. These vendors would

sell pre-encoded farecards at the two price levels. If this alternative were implemented, the passenger flow distribution would change slightly (based on results of JPL analysis). According to the JPL report, 74 percent of the passengers would enter the system and proceed directly to the entry gates, 5 percent would utilize the existing farecard vendors, and 21 percent would utilize the fast vendors due to their increased reliability. In addition, the fast vendors would increase in the use of add-fares to 12 percent. To estimate the reliability of the fast vendors, the bill verifier reliability was used. Since many of the coin and ticket transport problems will be eliminated, the bill verifier element reliability provided a logical estimate. A new ADT per failure for fast vendors was also calculated based on the average down time per bill jam. Table 6-4 summarizes the data used for the fast-vendor system analysis. The data in Table 6-4 are a combination of the 1980 retrofit data and the estimated performance data for fast vendors.

TABLE 6-4. RELIABILITY AND ADT FOR $1 AND $5 FAST VENDORS, FARRAGUT WEST, 18TH STREET, 1980

AFC EQUIPMENT	RELIABILITY	UNRELIABILITY	ADT IN MINUTES
Entry Gates	0.9996	0.0004	11.43
Farecard Vendors	0.9962	0.0038	4.01
$1 and $5 Fast Vendors	0.9983	0.0017	5.50
Exit Gates	0.9996	0.0004	11.43
Add-Fares	0.9943	0.0057	2.32

Figure 6-2 shows the new passenger flow distribution for the $1 and $5 fast vendor alternative. Applying the data to the formula results in:

$$P(f) = (0.0042)(0.05) + (0.0021)(0.21) + (0.0004)(0.74) + \frac{(0.0061)(0.12) + (0.0004)(1.00)}{0.05 + 0.21 + 0.74 + 0.12 + 1.00}$$

$$P(f) = 0.0010, \text{ or system reliability} = 0.9990$$

The results of the failure calculation show that 10 passengers out of 10,000 will experience a failure in the AFC equipment.

The new ADT for $1 and $5 fast vendors was utilized along with the new passenger flow distribution to calculate the average down time per system failure:

$$ADT = (11.43 + 4.01)(0.05) + (11.43 + 5.50)(0.21) + (11.43)(0.74) + \frac{(11.43 + 2.32 + 11.43)(0.12) + (11.43)(1.00)}{0.05 + 0.21 + 0.74 + 0.12 + 1.00}$$

$$ADT = 12.85$$

The $1 and $5 fast vendors reduced the number of passengers encountering a failure, but increased the average down time for AFC equipment failures.

6.4 IMPACT OF ONE- AND TWO-RIDE FAST VENDORS

Another alternative for AFC equipment is one- and two-ride fast vendors. These vendors would sell one- and two-ride tickets for an exact fare, and bill changers would be installed to supplement the vendors. Passenger flow distributions would be altered as shown in Figure 6-3. If a fast vendor accepts bills

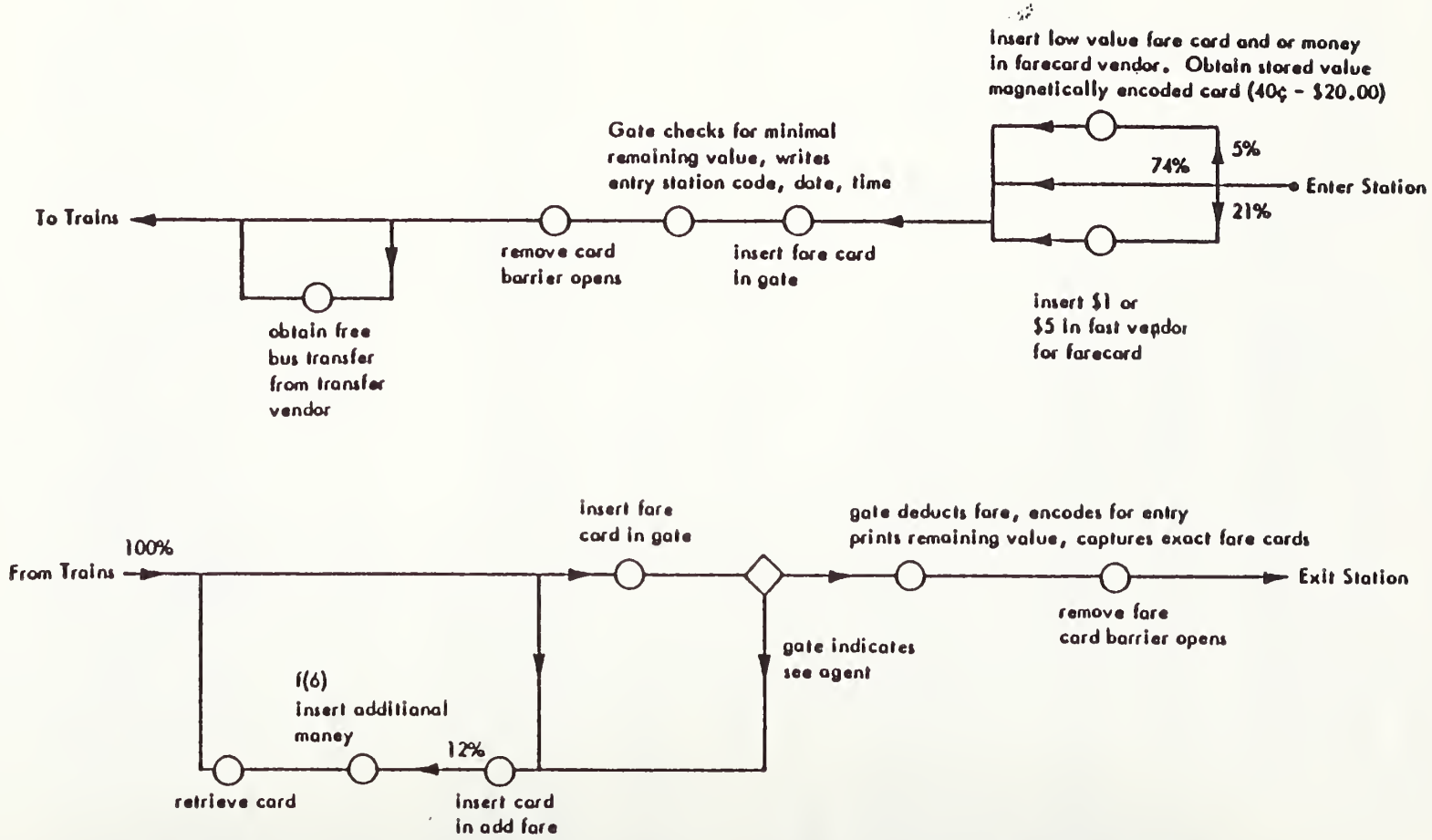


FIGURE 6-2. PASSENGER FLOW DISTRIBUTION FOR $1 AND $5 FAST VENDORS - WMATA*

*JPL, "Fare Collection Alternatives," Draft Interim Report, Contract NAS-7100, DOT AT-80015, January 1980.

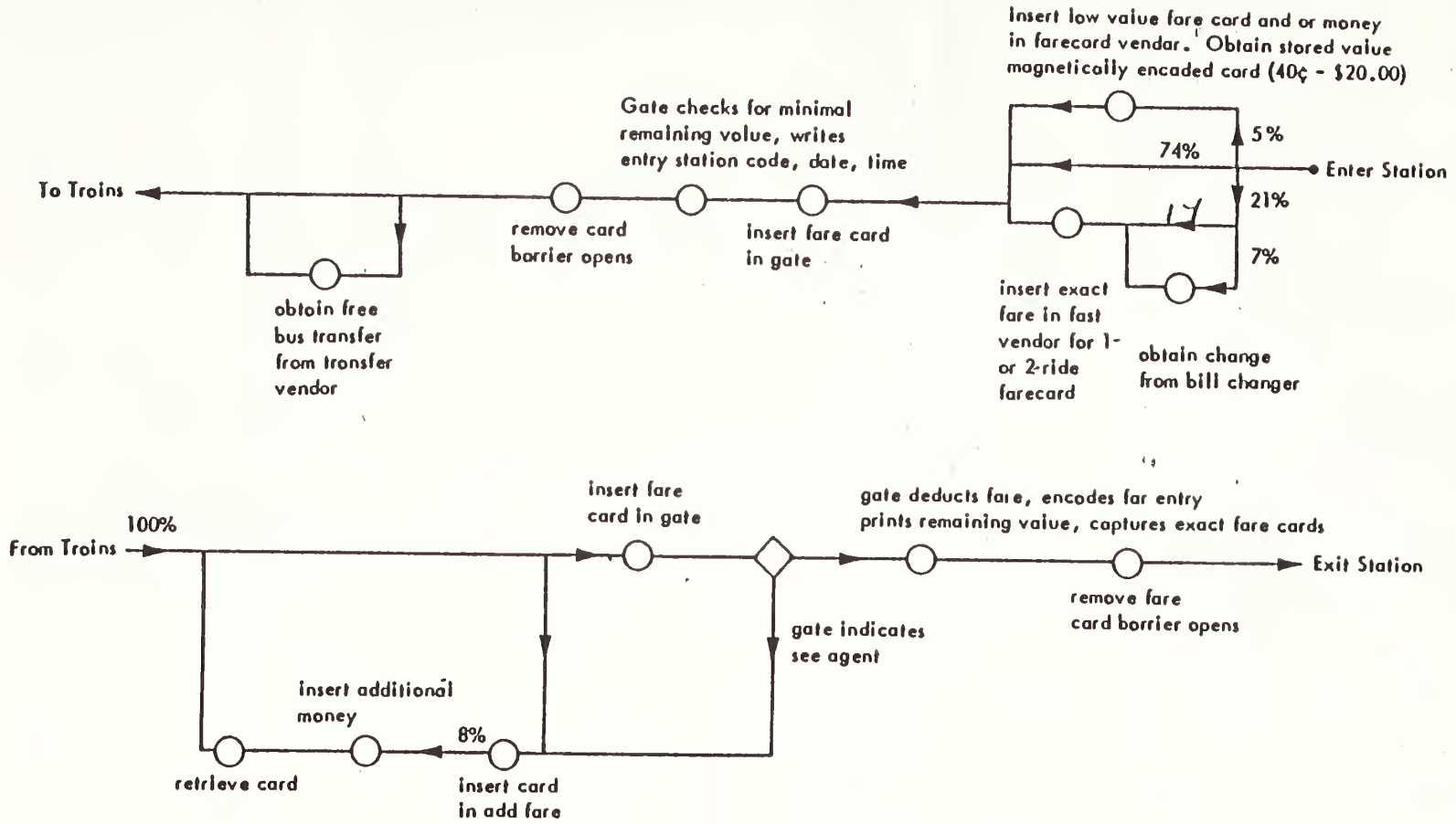


FIGURE 6-3. PASSENGER FLOW DISTRIBUTION FOR ONE-AND TWO-RIDE FAST VENDORS

*JPL, "Fare Collection Alternatives," Draft Interim Report, Contract NAS-7100, DOT AT-80015, January 1980.

and coins, then the reliability of the vendor would approximate a normal vendor without farecard jams, (i.e., fewer farecard jams would occur as the tickets would be pre-encoded with a certain value). An estimate of one- and two-ride fast vendor reliability was derived by utilizing total transactions and total failures minus farecard jams. ADT was estimated to be the same as normal farecard vendors since farecard jams have roughly the same average duration as bill and coin jams. Table 6-5 summarizes the performance data utilized to calculate system reliability.

TABLE 6-5. RELIABILITY AND ADT FOR ONE- AND TWO-RIDE FAST VENDORS, FARRAGUT WEST, 18TH STREET, 1980

AFC EQUIPMENT	RELIABILITY	UNRELIABILITY	ADT IN MINUTES
Entry Gates	0.9996	0.0004	11.43
Farecard Vendors	0.9962	0.0038	4.01
One- and Two-Ride Fast Vendors	0.9965	0.0035	4.01
Bill Changer	0.9995*	0.0005	5.50**
Exit Gates	0.9996	0.0004	11.43
Add-Fares	0.9943	0.0057	2.32

*Estimate from JPL Report

**Estimated from average down time per bill jam for Farecard Vendors

Applying the data to the formula:

$$P(f) = (0.0042)(0.05) + (0.0039)(0.20) + (0.0044)(0.01) + (0.0004)(0.74) + \frac{(0.0061)(0.08) + (0.0004)(1.00)}{0.05 + 0.20 + 0.01 + 0.74 + 0.08 + 1.00}$$

$P(f) = 0.0011$ or system reliability = 0.9989

The results of the failure calculation indicate that 11 out of 10,000 passengers will encounter a failure.

The ADT for the bill changer and the new passenger flow distribution were utilized to calculate the average down time per system failure:

$$ADT = (11.43 + 4.01)(0.05) + (11.43 + 4.01)(0.20) + (11.43 + 4.01 + 5.50)(0.01) + \frac{(11.43)(0.74) + (11.43 + 2.32 + 11.43)(0.08) + (11.43)(1.00)}{0.05 + 0.20 + 0.01 + 0.74 + 0.08 + 1.00}$$

ADT = 12.49

The ADT is less than that of $1 and $5 fast vendors and approximately the same as Retrofit B alone.

6.5 IMPACT OF OPTIMUM AFC EQUIPMENT PERFORMANCE

A final alternative was to test the current system configuration assuming optimal performance of the equipment. For this study, optimal performance standards were defined as at least 10,000 transactions per farecard jam, or a reliability of 0.9999. If all AFC equipment met this performance level (i.e.,

10,000 transactions per failure), then the current system may have an overall reliability greater than or equal to other alternatives. To test this alternative, all AFC equipment was assigned a reliability of 0.9999. In addition, all AFC equipment was assigned the lowest of the ADT's utilized for the alternatives. The original passenger distribution flow was also utilized (Figure 6-1). Table 6-6 summarizes the data utilized to calculate system reliability.

TABLE 6-6. RELIABILITY AND ADT FOR OPTIMUM PERFORMANCE OF CURRENT AFC SYSTEM, FARRAGUT WEST, 18TH STREET

AFC EQUIPMENT	RELIABILITY	UNRELIABILITY	ADT IN MINUTES ALL FAILURES
Entry Gates	0.9999	0.0001	3.42
Vendors	0.9999	0.0001	4.01
Exit Gates	0.9999	0.0001	3.42
Add-Fares	0.9999	0.0001	2.32

Applying the data to the equation results in:

$$P(f) = \frac{(0.0002)(0.33) + (0.0001)(0.67) + (0.0002)(0.07)}{0.33 + 0.67 + 0.07 + 1.00} + \frac{(0.0001)(1.00)}{0.33 + 0.67 + 0.07 + 1.00}$$

$P(f) = 0.0001$, or system reliability = 0.9999

The average down time per failure was calculated as follows:

$$ADT = \frac{(3.42 + 4.01)(0.33) + (3.42)(0.67)}{0.33 + 0.67 + 0.07 + 1.00}$$

$$+ \frac{(3.42 + 2.32 + 3.42)(0.07) + (3.42)(1.00)}{0.33 + 0.67 + 0.07 + 1.00}$$

$$ADT = 4.25 \text{ minutes}$$

6.6 SUMMARY

If all AFC equipment had reliabilities of 0.9999, the current system would also have the same overall reliability. The average down time per failure was estimated according to past observable down times, so the low overall ADT may be achievable.

When all four alternatives were compared (Table 6-7), the current system operating under optimal performance (at least 10,000 transactions per failure) had the best system reliability and ADT per failure. The $1 and $5 fast vendors had the second best system reliability, followed closely by the one- and two-ride vendors. Overall, a more extensive analysis of the costs and benefits of the various alternatives is needed before any conclusive recommendations can be made.

TABLE 6-7. COMPARISON OF AFC ALTERNATIVES: SYSTEM RELIABILITY AND ADT PER FAILURE, FARRAGUT WEST, 18TH STREET

ALTERNATIVE	SYSTEM RELIABILITY FAILURES PER 10,000 TRANSACTIONS	ADT* PER FAILURE
1978-1979 System	26	6.73
Retrofit B	12	12.53
$1 and $5 Fast Vendors	10	12.85
One- and Two-Ride Fast Vendors	11	12.49
Optimum Performance of AFC Equipment	1	4.25

*Time in Minutes

APPENDIX 1

DATA COLLECTION PROCEDURES AND SAMPLE SURVEY FORMS

Data Collection Procedures

Pre-Data Collection

1) Arrive at mezzanine one-half hour prior to scheduled data collection. Utilize this time to manually record transaction data for each machine. Be sure to bring a flashlight. Utilize the attached DADS form to record the information.

2) Record Entry (E) or Exit (X) mode for each faregate.

3) Record date of survey on data collection form.

Start

1) Activate DADS printer to obtain first reading.

2) Record begin time of survey on data collection form.

3) Collect data.

- Remarks - Try to obtain information on all H and O failure classifications.

  - AWPS = machine out-of-service due to awaiting parts.

Finish

1) Activate DADS printer to obtain second reading.

2) Record final DADS time and machine status for each machine.

3) Record final DADS time on data collection form.

4) Manually record transaction data for each machine. Utilize the same DADS form.

5) Collect DADS tapes.

DADS FORM

MEZZANINE _____

DATE: _____

GATE #	TIME	PATRONS OUT	ZERO FARECARDS CAPTURED	FARECARDS USED A	FARECARDS USED B	REVENUE	PATRONS IN	
130								

DADS FORM

MEZZANINE _____

DATE: _____

GATE #	TIME	PATRONS OUT	ZERO FARECARDS CAPTURED	FARECARDS USED A	FARECARDS USED B	REVENUE	PATRONS IN	

13E

SAMPLE SURVEY SHEET

Keys: B = Bill Jam; C = Coin Jam; J = Farecard Jam; V = Failure to Verify; F = Money Container Full; O = Out-of-Service; H = Hard Failure; E = Entry; X = Exit; R = Returned to Service

Farragut Headt. 10th St.
Date: 2/25/80
Time: 0700

DAY'S TIME	AISLE							VENDORS						ADD-FARES		REMARKS
	10	11	12	13	18	19	20	30	31	32	33	34	35	50	51	
	E	X	X	E	X	X										← record E or X
0700					H											H 18, Awl's
0701								J								
0702											B					
0703								K								
0704										C						- Bent coin H 32
0705		V/B								K	K					
0710		V/K					J									
0711		V/B											O			H H, constant J
0715		T						H					R			H 35 - no explanation
0730		R					R			V/B						
0735		T														
0736		R						R								H H, put OOS by Mtd.
0739		H								K						tech. called
0740																
0743												F				money container Full H33
0745									V							- failure to verify
0750																
0752									R							- returned to service
0758								H								- OOS #30, tech. called
0815																broken door
0831																
0849																
0900																
0930	R	O	R	O	O	R	R	O	R	R	R	O	R			

SAMPLE OF DADS TAPES

ADDFARE (50)

```
0000216435      $ Change
0000154150      $ Coins Accepted
0000408850      $ Amount Issued
0000001455      $5 Bills Issued
0000002032      $1 Bills Accepted
0000002830      Successful Transactions
0000005060
6763661430

0000005049
0763661430



0000005013
0763661429
```

REV GATE (12)

```
0000000369      Patrons In
0000460430      Fare Extracted
0000000195      'B'
0000006243      'A'
0000000086      Zero Value Cap
0000006447      Patrons Out
0000005012
0763661429
```

EXIT GATE (11)

```
0000006520      Patrons In
0001285250      Fare Extracted
0000000167      'B'
0000000177      'A'
0000000195      Zero Value Cap
0000003242      Patrons Out
0000005011
0763661429

0000005610
0763661429
```

```
0000005031
0763661429

VENDOR (30)

0000077415      $ Change
0001172475      $ Old Farecards
0000192225      $ Bonus Paid
0001662770      $ Amount Issued
0000697085      $ Coins Accepted
0000000293      Farecards Not Verified
0000031702      Farecards Accepted
0000025253      No. Successful Transactions
0000008646      $5 Bills Accepted
0000089901      $1 Bills Accepted
0000005830
0763661429



0000005021
0763661429

ENTRY GATE (20)

0000000000
0000000000
0000000000
0000000000
0000000000
0000002528      Patrons In
0000005020
0763661429
```

APPENDIX 2

CHI-SQUARE TEST FOR EQUALITY OF PROPORTIONS AND APPLICATION OF CHI-SQUARE TO AFC DATA

Chi-Square Test for Equality of Proportions

Suppose we have K vendors, each with its overall and element reliabilities. Due to random variations, the vendors and their elements are expected to have different reliabilities. The Chi-Square Statistic measures whether these differences are attributable to chance, or whether these differences actually represent vendors with different performance characteristics (i.e., some vendors may perform better or worse than others).

This Chi-Square Test helps to determine whether the vendors essentially have equal reliabilities or whether some perform better than others.

Application

Let n_i = total number of transactions of the i^{th} vendor

x_i = total number of successful transactions of the i^{th} vendor

$R_i = \frac{x_i}{n_i}$ reliability of the i^{th} vendor

$R = \frac{\Sigma x_i}{\Sigma n_i}$ overall reliability of the system

k = total number of vendors

The Statistic:

$$U = \sum_{i=1}^{k} \frac{(x_i - n_i R)^2}{n_i R (1 - R)}$$ has a Chi-square distribution with

k - 2 degrees of freedom.

The statistic U tests the following:

All vendors have equal reliabilities versus some have different reliabilities.

If U $\leq$ a table X^2-value, we accept the hypothesis of equal reliabilities, otherwise we say that some vendors have different reliabilities.

1. Application of chi-square to overall farecard vendor reliability by mezzanine:

MEZZANINE	n_i	x_i	U
DuPont Circle	18,806	18,708	21.80
Brookland	13,912	13,796	0.0025
Silver Spring	30,257	29,952	11.65
Farragut - 17th Street	21,078	20,861	10.20
Farragut - 18th Street	21,957	21,787	0.8294
Rosslyn	47,973	47,598	1.3602
			= 45.84

R = 0.9917

K - 2 degrees of freedom = 4

Chi-square for 4 degrees of freedom at 95 percent confidence = 9.488

45.84 > 9.488, therefore, the mezzanines have different vendor reliabilities

APPENDIX 3

T-TEST OF PROPORTIONS AND APPLICATION OF T-TEST TO AFC DATA

The T-Test of Proportions

A particular application of the T-test is to determine whether a vendor (or element in the vendor) exhibits a reliability of a specified minimum value (see equation (1) for derivation of minimum value). The T-test measures whether a vendor is unacceptable or acceptable with respect to its reliability. Thus, this T-test establishes a minimum acceptable reliability for each vendor based on its volume of use and an overall system reliability, and it compares the vendor reliability with the minimum expected reliability.

(1) Derivation of Minimum Acceptable Reliability

Let X_i = number of successful transactions by the i^{th} vendor

n_i = number of transactions by the i^{th} vendor

Then $R_i = \frac{x_i}{n_i}$ = reliability of the i^{th} vendor.

Let R = overall reliability of the system.

Thus the i^{th} vendor has an acceptable reliability at the 95 percent level if:

$$R_i \geq R - 1.645 \sqrt{\frac{R_i (1 - R_i)}{n_i}}$$

Another application of the T-test is to test whether retrofits improve vendor reliabilities. The T-test determines if increases (if any) in reliabilities from retrofitting are due to chance or due to improvements in vendor performance. The application of this test is that of the two-sample t-test for

proportions. A minimum increase in reliability due to retrofitting is determined, and if the actual increase is greater than the minimum increase, the retrofitting significantly improves the reliability of a vendor.

(2) Derivation of minimum increase

Let R_R = retrofit reliability

R_N = pre-retrofit reliability

n_R = total number of transactions involving retrofitting

n_N = total number of transactions before retrofitting

At the 95 percent level, retrofitting improves reliabilities if

$$R_R - R_N \geq 1.645 \sqrt{\frac{R_R\ (1 - R_R)}{n_R} + \frac{R_N\ (1 - R_N)}{n_N}}$$

at the 99 percent level,

$$R_R - R_N \geq 2.331 \sqrt{\frac{R_R\ (1 - R_R)}{n_R} + \frac{R_N\ (1 - R_N)}{n_N}}$$

1) Application of t-test to overall farecard vendor reliability by mezzanine.

R = 0.9917

MEZZANINE	R_i	R_i^*
DuPont Circle	0.9948	0.9908
Brookland	0.9917	0.9904
Silver Spring	0.9989*	0.9908
Farragut - 17th Street	0.9897*	0.9906
Farragut - 18th Street	0.9923	0.9909
Rosslyn	0.9922	0.9910

*less than expected R given the sample size at the mezzanine

APPENDIX 4

TOTAL AND ELEMENT MONTHLY RELIABILITY AND MEAN TRANSACTIONS PER FAILURE FOR FARECARD VENDORS, 1978-1979

Mezzanine: Dupont 1978-1979
Vendor: 30

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
November	0.9861	72	0.9959	242	0.9959	245	0.9972	360	0.9750	40
December	0.9914	116	0.9983	581	1.00	331/0	1.00	463/0	0.9892	93
January	1.00	385/0	1.00	487/0	1.00	215/0	1.00	385/0	1.00	385/0
February	1.00	513/0	1.00	870/0	1.00	291/0	1.00	513	1.00	513/0
March	0.9947	189	1.00	474/0	0.9962	263	1.00	378	0.9921	126
April	1.00	167/0	1.00	292/0	0.9896	96	1.00	167/0	0.9940	167
May	0.9779	45	1.00	371/0	1.00	216/0	1.00	272/0	0.9779	45
August	1.00	314/0	1.00	360/0	1.00	309/0	1.00	314/0	1.00	314/0
Total	0.9940	168	0.9992	1306	0.9985	655	0.9996	2852	0.9916	119

$T/J = \frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

$C/C = \frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

$B/B = \frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

$T/O = \frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

$T/T = \frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

$R = \text{Reliability} = \frac{\text{Successes}}{\text{Transactions}}$

Mezzanine: Dupont 1978-1979
Vendor: 31

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
November	1.00	446/0	0.9982	543	0.9970	329	1.00	446/0	0.9955	223
December	0.9919	124	1.00	509	1.00	250	0.9946	186	0.9866	74
January	1.00	209/0	1.00	203/0	1.00	145/0	0.9856	70	0.9856	70
February	0.9986	736	1.00	1028	1.00	450	1.00	736/0	0.9986	736
March	0.9959	244	0.9981	529	1.00	155/0	0.9836	61	0.9754	41
April	0.9952	209	1.00	382/0	1.00	139/0	0.9904	105	0.9856	70
May	1.00	338/0	1.00	452/0	1.00	257/0	1.00	338/0	1.00	338/0
August	1.00	308/0	1.00	417/0	0.9955	224	1.00	308	0.9968	308
Total	0.9979	477	0.9995	2031	0.9990	975	0.9962	260	0.9927	136

$T/J = \frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

$C/C = \frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

$B/B = \frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

$T/O = \frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

$T/T = \frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

$R = \text{Reliability} = \frac{\text{Successes}}{\text{Transactions}}$

Mezzanine: Dupont 1978-1979
Vendor: 32

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
November	1.00	132/0	1.00	139/0	1.00	107/0	0.9848	66	0.9848	66
December	0.9957	232	0.9982	562	0.9970	336	0.9978	463	0.9892	93
January	1.00	568/0	1.00	699/0	1.00	373/0	0.9982	568	0.9982	568
February	1.00	840/0	1.00	986/0	1.00	606/0	1.00	840/0	1.00	840/0
March	0.9909	110	1.00	635/0	0.9967	299	1.00	439/0	0.9886	88
April	0.9955	223	0.9955	220	0.9946	184	0.9955	223	0.9821	56
May	0.9976	417	1.00	465/0	1.00	322/0	1.00	417/0	0.9976	417
August	1.00	311/0	1.00	536/0	1.00	200/0	1.00	311/0	1.00	311/0
Total	0.9976	424	0.9995	2121	0.9988	809	0.9985	679	0.9947	189

$T/J = \frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

$C/C = \frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

$B/B = \frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

$T/O = \frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

$T/T = \frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

$R = \text{Reliability} = \frac{\text{Successes}}{\text{Transactions}}$

Mezzanine: Dupont 1978-1979
Vendor: 38

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
November	0.9987	788	0.9979	318	1.00	560/0	1.00	788/0	0.9949	197
December	0.9945	181	0.9981	521	1.00	367/0	0.9982	544	0.9890	91
January	1.00	425/0	1.00	577/0	1.00	297/0	1.00	425/0	1.00	425/0
February	0.9986	738	0.9997	3150	1.00	947/0	1.00	1476/0	0.9980	492
March	0.9985	650	1.00	936/0	1.00	432/0	1.00	[illegible]	[illegible]	650
April	1.00	561/0	1.00	674/0	1.00	376/0	1.00	561/0	1.00	561/0
May	1.00	714/0	1.00	838/0	1.00	468/0	1.00	714/0	1.00	714/0
August	1.00	286/0	1.00	409/0	0.9805	51	1.00	286/0	0.9825	57
Total	0.9987	778	0.9993	1430	0.9989	913	0.9996	2722	0.9965	287

$T/J = \frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

$C/C = \frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

$B/B = \frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

$T/O = \frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

$T/T = \frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

$R = \text{Reliability} = \frac{\text{Successes}}{\text{Transactions}}$

Mezzanine: Dupont 1978-1979
Vendor: 39

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
November	1.00	526/0	0.9962	260	1.00	372/0	0.9943	175	0.9886	88
December	0.9959	244	1.00	339/0	1.00	193/0	0.9836	61	0.9795	49
January	1.00	549/0	1.00	721/0	1.00	394/0	1.00	549/0	1.00	549/0
February	1.00	968/0	1.00	1471/0	1.00	601/0	1.00	968/0	1.00	968/0
March	0.9984	618	1.00	1719/0	1.00	407/0	1.00	618/0	0.9984	618
April	0.9936	157	1.00	534/0	1.00	167/0	1.00	314/0	0.9936	157
May	0.9987	763	1.00	826/0	1.00	453/0	1.00	763/0	0.9987	763
August	1.00	273/0	1.00	279/0	1.00	156/0	0.9963	273	0.9963	273
Total	0.9988	851	0.9996	2223	1.00	2743/0	0.9981	532	0.9962	266

$T/J = \frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

$C/C = \frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

$B/B = \frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

$T/O = \frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

$T/T = \frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

$R = \text{Reliability} = \frac{\text{Successes}}{\text{Transactions}}$

Mezzanine: Brookland 1978-1979
Vendor: 30

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
November	0.9984	612	1.00	745/0	1.00	430/0	0.9967	306	0.9951	204
January	1.00	359/0	0.9947	190	1.00	238/0	0.9889	90	0.9777	45
February	0.9980	502	1.00	606/0	1.00	343/0	0.9940	167	0.9920	126
March	0.9977	440	1.00	592/0	1.00	281/0	1.00	44/0	0.9977	440
May	1.00	916/0	1.00	1047/0	1.00	631/0	0.9989	916	0.9989	916
June	0.9958	236	0.9993	1508	1.00	782/0	0.9992	1181	0.9941	169
August	1.00	539/0	0.9977	437	1.00	317/0	1.00	539/0	0.9963	270
Total	0.9982	569	0.9989	876	1.00	2722/0	0.9976	414	0.9943	175

$T/J = \frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

$C/C = \frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

$B/B = \frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

$T/O = \frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

$T/T = \frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

$R = \text{Reliability} = \frac{\text{Successes}}{\text{Transactions}}$

Mezzanine: Brookland 1978-1979
Vendor: 31

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
November	1.00	581/0	0.9986	714	0.9970	335	0.9983	581	0.9948	194
January	0.9916	120	0.9988	853	1.00	369/0	0.9983	598	0.9916	85
February	0.9962	261	0.9973	368	0.9968	312	0.9962	261	0.9866	75
March	1.00	516/0	0.9986	722	0.9878	82	0.9981	516	0.9884	86
May					Out of Service					
June	0.9973	373	0.9948	192	1.00	204/0	0.9839	62	0.9732	37
August	0.9971	348	0.9802	50	1.00	264/0	0.9971	348	0.9741	39
Total	0.9969	326	0.9962	264	0.9967	302	0.9959	245	0.9857	70

$T/J = \frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

$C/C = \frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

$B/B = \frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

$T/O = \frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

$T/T = \frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

$R = \text{Reliability} = \frac{\text{Successes}}{\text{Transactions}}$

Mezzanine: Brookland 1978-1979
Vendor: 32

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
November					Out of Service					
January	1.00	517/0	0.9969	320	1.00	339/0	0.9981	517	0.9942	172
February	1.00	571/0	0.9988	817	1.00	346/0	1.00	571/0	0.9982	571
March	1.00	333/0	0.9977	441	1.00	210/0	0.9970	333	0.9940	167
May	0.9986	737	0.9985	658	0.9944	180	0.9946	184	0.9878	82
June	0.9988	834	0.9994	1614	0.9974	387	1.00	834/0	0.9964	278
August	0.9959	244	0.9903	103	0.9968	317	0.9918	122	0.9754	41
Total	0.9989	870	0.9978	445	0.9980	490	0.9971	348	0.914	116

$T/J = \frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

$C/C = \frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

$B/B = \frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

$T/O = \frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

$T/T = \frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

$R = \text{Reliability} = \frac{\text{Successes}}{\text{Transactions}}$

Mezzanine: Brookland 1978-1979
Vendor: 33

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
November	0.9987	745	0.9977	430	1.00	530/0	1.00	745/0	0.9960	248
January	1.00	323/0	0.9915	118	1.00	198/0	0.9938	162	0.9814	54
February	0.9932	148	1.00	186/0	1.00	97/0	0.9865	74	0.9797	49
March	0.9981	533	1.00	782/0	1.00	328/0	0.9981	533	0.9962	267
May	1.00	708/0	1.00	971/0	1.00	476/0	0.9986	708	0.9986	708
June					Out of Service					
August	1.00	488/0	0.9971	349	1.00	317/0	0.9980	488	0.9939	163
Total	0.9990	982	0.9980	496	1.00	1946/0	0.9976	421	0.9939	164

T/J = Total Transactions / Total Farecard Jams

C/C = Total Coins Inserted / Total Coin Jams

B/B = Total Bills Inserted / Total Bill Jams

T/O = Total Transactions / Total "Other" Failures

T/T = Total Transactions / Total Jams and "Other" Failures

R = Reliability = Successes / Transactions

Mezzanine: Silver Spring 1978-1979
Vendor: 30

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October	0.9912	114	0.9785	47	0.9965	288	0.9965	286	0.9615	26
December	0.9982	559	0.9968	310	1.00	543/0	0.9982	559	0.9928	140
January	0.9986	736	1.00	831/0	1.00	707/0	0.9986	736	0.9973	368
February	0.9971	351	1.00	854/0	1.00	655/0	1.00	702/0	0.9971	351
March	1.00	808/0	0.9978	449	0.9974	381	1.00	808/0	0.9950	202
April	0.9970	335	1.00	338/0	1.00	321/0	1.00	335/0	0.9970	335
May	0.9945	181	0.9946	184	0.9963	268	0.9926	136	0.9779	45
June	0.9966	296	0.9927	136	1.00	333/0	0.9966	296	0.9831	59
Total	0.9969	325	0.9955	222	0.9986	739	0.9980	506	0.9886	86

$T/J = \frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

$C/C = \frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

$B/B = \frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

$T/O = \frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

$T/T = \frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

$R = \text{Reliability} = \frac{\text{Successes}}{\text{Transactions}}$

Mezzanine: Silver Spring 1978-1979
Vendor: 31

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October	1.00	660/0	0.9933	150	0.9918	122	0.9985	660	0.9833	60
December	0.9957	231	1.00	183/0	0.9957	232	1.00	231/0	0.9913	116
January	1.00	361/0	0.9973	373	1.00	343/0	0.9945	181	0.9917	120
February	1.00	309/0	1.00	480/0	1.00	231/0	0.9968	309	0.9968	309
March					Out of Service					
April	1.00	188/0	1.00	324/0	0.9934	152	0.9894	94	0.9840	63
May	1.00	871/0	1.00	1092/0	1.00	824/0	1.00	871/0	1.00	871/0
June	0.9812	53	1.00	525/0	1.00	443/0	0.9906	106	0.9718	35
Total	0.9970	338	0.9984	621	0.9975	405	0.9967	305	0.9895	95

$T/J = \frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

$C/C = \frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

$B/B = \frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

$T/O = \frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

$T/T = \frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

$R = \text{Reliability} = \frac{\text{Successes}}{\text{Transactions}}$

Mezzanine: Silver Spring 1978-1979
Vendor: 32

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October	0.9981	530	0.9984	633	1.00	482/0	1.00	530/0	0.9962	265
December	1.00	577/0	0.9925	134	0.9982	553	0.9948	192	0.9844	64
January	0.9982	549	0.9976	421	1.00	607/0	0.9982	549	0.9964	183
February	1.00	557/0	1.00	414/0	1.00	523/0	1.00	557/0	1.00	557/0
March	1.00	669/0	0.9978	465	1.00	696/0	1.00	669/0	0.9985	669
April	0.9709	34	0.9868	76	1.00	100/0	0.9903	103	0.9515	21
May	0.9865	74	0.9985	662	1.00	611/0	0.9983	594	0.9832	59
June	0.9864	74	0.9986	706	1.00	723/0	0.9932	148	0.9783	46
Total	0.9947	188	0.9973	368	0.9998	4295	0.9975	392	0.9893	94

$T/J = \frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

$C/C = \frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

$B/B = \frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

$T/O = \frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

$T/T = \frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

$R = \text{Reliability} = \frac{\text{Successes}}{\text{Transactions}}$

Mezzanine: Silver Spring 1978-1979
Vendor: 33

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October					Out of Service					
December	0.9908	108	0.9886	75	1.00	434/0	0.9945	180	0.9723	36
January	0.9957	235	1.00	608/0	1.00	400/0	0.9979	470	0.9936	157
February	0.9935	155	1.00	428/0	0.9956	230	0.9903	104	0.9806	52
March	1.00	189/0	1.00	307/0	1.00	154/0	1.00	189/0	1.00	189/0
April	1.00	308/0	1.00	337/0	1.00	310/0	0.9968	308	0.9968	308
May	1.00	592/0	1.00	392/0	0.9967	300	1.00	592/0	0.9966	296
June	0.9981	534	0.9924	133	1.00	690/0	0.9925	134	0.9831	59
Total	0.9966	294	0.9965	285	0.9989	939	0.9959	245	0.9878	82

$T/J = \frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

$C/C = \frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

$B/B = \frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

$T/O = \frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

$T/T = \frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

$R = \text{Reliability} = \frac{\text{Successes}}{\text{Transactions}}$

Mezzanine: Silver Spring 1978-1979
Vendor: 34

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October	0.9961	259	0.9978	460	0.9970	332	0.9949	195	0.9859	71
December	0.9984	623	1.00	744/0	0.9981	531	0.9968	312	0.9936	156
January	1.00	570/0	1.00	930/0	1.00	398/0	1.00	570/0	1.00	570/0
February	1.00	523/0	1.00	719/0	0.9952	207	0.9885	87	0.9847	65
March	0.9987	787	1.00	1080/0	1.00	710/0	1.00	787/0	0.9987	787
April	1.00	370/0	1.00	416/0	1.00	333/0	0.9973	370	0.9973	370
May	1.00	431/0	1.00	591/0	1.00	363/0	0.9977	431	0.9977	431
June	1.00	914/0	0.9991	1074	0.9989	886	0.9967	305	0.9945	183
Total	0.9990	999	0.9995	2158	0.9986	716	0.9968	294	0.9938	161

$T/J = \frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

$C/C = \frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

$B/B = \frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

$T/O = \frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

$T/T = \frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

$R = \text{Reliability} = \frac{\text{Successes}}{\text{Transactions}}$

Mezzanine: Silver Spring 1978-1979
Vendor: 35

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October	0.9955	224	0.9973	375	0.9967	302	1.00	672/0	0.9896	96
December	0.9911	112	0.9980	511	1.00	530/0	0.9929	141	0.9822	56
January					Out of Service					
February	0.9962	264	0.9982	569	0.9973	377	1.00	527/0	0.9924	132
March					No DADS Data					
April					No DADS Data					
May	1.00	537/0	1.00	274/0	0.9966	299	1.00	537/0	0.9963	269
June	1.00	716/0	0.9959	243	1.00	703/0	1.00	716/0	0.9958	239
Total	0.9967	301	0.9975	405	0.9982	562	0.9987	754	0.9914	116

T/J = Total Transactions / Total Farecard Jams

C/C = Total Coins Inserted / Total Coin Jams

B/B = Total Bills Inserted / Total Bill Jams

T/O = Total Transactions / Total "Other" Failures

T/T = Total Transactions / Total Jams and "Other" Failures

R = Reliability = Successes / Transactions

Mezzanine: Silver Spring 1978-1979
Vendor: 36

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October	0.9944	180	1.00	419/0	1.00	355/0	1.00	359/0	0.9944	180
December	0.9922	129	0.9981	539	0.9969	327	0.9948	193	0.9819	55
January	0.9919	124	0.9963	269	0.9929	142	0.9973	371	0.9784	46
February	0.9926	136	0.9972	354	0.9936	156	0.9975	408	0.9828	58
March	1.00	522/0	1.00	733/0	1.00	466/0	1.00	522/0	1.00	522/0
April	0.9959	247	1.00	281/0	1.00	244/0	1.00	247/0	0.9959	247
May	1.00	727/0	1.00	1121/0	0.9967	306	0.9972	364	0.9945	182
June	1.00	239/0	0.9983	578	1.00	114/0	1.00	239/0	0.9958	239
Total	0.9963	272	0.9989	913	0.9974	387	0.9982	543	0.9908	109

$T/J = \frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

$C/C = \frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

$B/B = \frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

$T/O = \frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

$T/T = \frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

$R = \text{Reliability} = \frac{\text{Successes}}{\text{Transactions}}$

Mezzanine: Silver Spring 1978-1979
Vendor: 40

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October	1.00	444/0	1.00	517/0	1.00	450/0	0.9977	444	0.9977	444
December	0.9667	30	1.00	320/0	1.00	276/0	0.9926	135	0.9593	25
January	0.9974	383	0.9838	62	0.9976	411	0.9948	192	0.9739	38
February					No DADS Data					
March	1.00	206/0	0.9926	136	1.00	192/0	1.00	206/0	0.9903	103
April					Out of Service					
May					Out of Service					
June					Out of Service					
Total	0.9923	130	0.9946	185	0.9992	1329	0.9962	261	0.9816	54

$T/J = \frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

$C/C = \frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

$B/B = \frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

$T/O = \frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

$T/T = \frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

$R = \text{Reliability} = \frac{\text{Successes}}{\text{Transactions}}$

Mezzanine: Silver Spring 1978-1979
Vendor: 41

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October	1.00	444/0	1.00	451/0	0.9969	327	0.9932	148	0.9910	111
December	0.9885	87	0.9952	210	0.9972	363	0.9971	349	0.9771	44
January	1.00	299/0	0.9977	435	0.9963	270	0.9866	75	0.9799	50
February					No DADS Data					
March	1.00	248/0	1.00	303/0	1.00	245/0	1.00	248/0	1.00	248/0
April	0.9958	240	1.00	240/0	1.00	254/0	1.00	240/0	0.9958	240
May	0.9950	202	1.00	812/0	1.00	573.0	1.00	605/0	0.9950	202
June	0.9969	323	0.9963	268	1.00	608.0	0.9984	645	0.9907	108
Total	0.9965	283	0.9983	577	0.9989	880	0.9968	314	0.9901	101

$T/J = \frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

$C/C = \frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

$B/B = \frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

$T/O = \frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

$T/T = \frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

$R = \text{Reliability} = \frac{\text{Successes}}{\text{Transactions}}$

Mezzanine: Farragut West - 17th Street 1978-1979
Vendor: 30

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
November	0.9978	460	0.9990	1050	0.9985	666	1.00	920/0	0.9957	230
December	1.00	473/0	1.00	561/0	0.9912	114	0.9958	237	0.9894	95
January	0.9940	168	1.00	625/0	1.00	539/0	0.9980	505	0.9921	126
February	0.9975	397	1.00	408/0	0.9940	168	1.00	397/0	0.9924	132
March	1.00	324/0	1.00	345/0	0.9880	84	1.00	324/0	0.9907	108
April	1.00	399/0	1.00	448/0	0.9895	95	0.9975	399	0.9900	100
May	0.9966	294	1.00	79/0	0.9958	237	1.00	294	0.9932	147
June	0.9989	915	0.9989	965	0.9972	361	0.9989	915	0.9945	183
Total	0.9981	528	0.9996	2241	0.9956	225	0.9988	845	0.9929	141

$T/J = \frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

$C/C = \frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

$B/B = \frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

$T/O = \frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

$T/T = \frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

$R = \text{Reliability} = \frac{\text{Successes}}{\text{Transactions}}$

Mezzanine: Farragut West - 17th Street 1978-1979
Vendor: 31

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
November	0.9981	539	1.00	N/A	1.00	505/0	1.00	539/0	0.9981	539
December	0.9968	316	N/A	N/A	1.00	404/0	1.00	631/0	0.9968	316
January	0.9917	120	1.00	327/0	1.00	299/0	0.9972	360	0.9889	90
February	0.9947	188	1.00	304/0	0.9802	51	1.00	188/0	0.9840	63
March	1.00	308/0	1.00	301/0	0.9917	120	0.9740	39	0.9675	31
April	1.00	293/0	0.9976	423	0.9897	97	1.00	293/0	0.9898	98
May	1.00	329/0	1.00	448/0	0.9956	225	0.9970	329	0.9939	165
June	0.9985	675	1.00	935/0	0.9881	84	0.9970	338	0.9881	84
Total	0.9976	415	0.9993	1369	0.9950	199	0.9964	277	0.9901	101

T/J = Total Transactions / Total Farecard Jams

C/C = Total Coins Inserted / Total Coin Jams

B/B = Total Bills Inserted / Total Bill Jams

T/O = Total Transactions / Total "Other" Failures

T/T = Total Transactions / Total Jams and "Other" Failures

R = Reliability = Successes / Transactions

N/A = Not Available

Mezzanine: Farragut West - 17th Street 1978-1979
Vendor: 32

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
November	0.9894	94	1.00	981/0	0.9952	208	0.9973	377	0.9814	54
December	0.9968	312	1.00	821/0	1.00	504/0	0.9968	312	0.9936	156
January	1.00	510/0	0.9984	618	0.9897	97	0.9961	255	0.9863	73
February	1.00	446/0	1.00	492/0	0.9908	110	0.9978	446	0.9910	112
March	0.9903	103	1.00	231/0	0.8571	7	0.9708	34	0.9029	10
April	0.9976	425	0.9982	554	0.9966	292	1.00	-	0.9929	142
May	1.00	86/0	1.00	67/0	0.9605	25	0.9767	43	0.9419	17
June	0.9954	216	1.00	840/0	0.9890	91	0.9969	324	0.9845	65
Total	0.9966	293	0.9996	2302	0.9904	104	0.9960	248	0.9845	64

$T/J = \frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

$C/C = \frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

$B/B = \frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

$T/O = \frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

$T/T = \frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

$R = \text{Reliability} = \frac{\text{Successes}}{\text{Transactions}}$

Mezzanine: Farragut West - 17th Street 1978-1979
Vendor: 33

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
November	0.9968	310	1.00	189/0	0.9905	105	0.9978	465	0.9882	84
December	0.9907	108	0.9988	820	0.9911	113	1.00	650/0	0.9831	59
January	0.9967	305	0.9946	187	0.9885	87	0.9984	609	0.9803	51
February	0.9970	332	1.00	375/0	0.9834	60	1.00	332/0	0.9849	66
March	1.00	492/0	0.9979	477	1.00	403/0	1.00	492/0	0.9980	492
April	0.9779	45	1.00	109/0	0.9929	142	0.9779	45	0.9485	19
May	1.00	494/0	0.9981	517	1.00	403/0	1.00	494/0	0.9980	494
June					Out of Service					
Total	0.9959	243	0.9978	462	0.9926	135	0.9984	607	0.9868	76

T/J = Total Transactions / Total Farecard Jams

C/C = Total Coins Inserted / Total Coin Jams

B/B = Total Bills Inserted / Total Bill Jams

T/O = Total Transactions / Total "Other" Failures

T/T = Total Transactions / Total Jams and "Other" Failures

R = Reliability = Successes / Transactions

Mezzanine: Farragut West - 17th Street 1978-1979
Vendor: 34

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
November					Out of Service					
December	1.00	794/0	0.9981	983	0.9964	279	0.9975	397	0.9937	159
January	1.00	632/0	1.00	738/0	0.9887	89	0.9968	316	0.9889	90
February					Out of Service					
March	1.00	524/0	0.9980	510	1.00	431/0	1.00	524/0	0.9981	524
April	1.00	565/0	1.00	692/0	1.00	383/0	1.00	565/0	1.00	565/0
May	1.00	544/0	1.00	636/0	1.00	404/0	0.9982	544	0.9982	544
June	0.9965	288	0.9963	272	0.9887	89	0.9977	432	0.9815	54
Total	0.9992	1307	0.9989	875	0.9949	195	0.9982	560	0.9924	131

T/J = Total Transactions / Total Farecard Jams

C/C = Total Coins Inserted / Total Coin Jams

B/B = Total Bills Inserted / Total Bill Jams

T/O = Total Transactions / Total "Other" Failures

T/T = Total Transactions / Total Jams and "Other" Failures

R = Reliability = Successes / Transactions

Mezzanine: Farragut West - 17th Street 1978-1979
Vendor: 35

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
November					Out of Service					
December	0.9957	231	1.00	562/0	1.00	293/0	0.9935	154	0.9892	92
January	1.00	942/0	1.00	1221/0	0.9953	212	1.00	942/0	0.9968	314
February	0.9953	213	1.00	289/0	0.9779	45	0.9953	213	0.9765	43
March	0.9952	208	1.00	589/0	0.7500	4	0.9952	208/0	0.9856	69
April					Out of Service					
May	1.00	72/0	1.00	420/0	1.00	138/0	0.9722	36	0.9722	36
June	1.00	850/0	0.9975	398	0.9945	180	0.9976	425	0.9906	106
Total	0.9985	687	0.9993	1425	0.9937	159	0.9971	343	0.9905	106

T/J = Total Transactions / Total Farecard Jams

C/C = Total Coins Inserted / Total Coin Jams

B/B = Total Bills Inserted / Total Bill Jams

T/O = Total Transactions / Total "Other" Failures

T/T = Total Transactions / Total Jams and "Other" Failures

R = Reliability = Successes / Transactions

Mezzanine: Farragut West - 18th Street 1978-1979
Vendor: 30

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October	1.00	622/0	0.9988	854	0.9975	402	0.9968	311	0.9936	156
December	0.9982	552	1.00	1036/0	0.9973	365	1.00	552/0	0.9964	276
January	0.9960	247	0.9982	570	1.00	399/0	1.00	494/0	0.9939	165
February	0.8800	8	1.00	169/0	1.00	33/0	0.9200	13	0.8000	5
March	0.9885	87	1.00	313/0	1.00	197/0	1.00	261/0	0.9885	87
April	0.9964	280	0.9985	677	0.9974	382	1.00	560/0	0.9929	140
May	0.9983	599	1.00	853/0	1.00	378/0	0.9983	599	0.9967	300
June	0.9934	152	1.00	362/0	1.00	223/0	0.9934	152	0.9868	76
Total	0.9951	202	0.9994	1611	0.9987	793	0.9974	382	0.9907	108

T/J = Total Transactions / Total Farecard Jams

C/C = Total Coins Inserted / Total Coin Jams

B/B = Total Bills Inserted / Total Bill Jams

T/O = Total Transactions / Total "Other" Failures

T/T = Total Transactions / Total Jams and "Other" Failures

R = Reliability

Mezzanine: Farragut West - 18th Street 1978-1979
Vendor: 31

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October	0.9984	640	1.00	869/0	0.9978	450	1.00	640/0	0.9969	320
December	0.9985	646	1.00	902/0	1.00	446/0	1.00	646/0	0.9985	646
January	1.00	512/0	1.00	512/0	0.9954	217	1.00	512/0	0.9961	256
February	0.9990	996	1.00	1491/0	1.00	576/0	1.00	996/0	0.9990	996
March	0.9958	236	1.00	371/0	1.00	122/0	1.00	236/0	0.9958	236
April	1.00	220/0	1.00	297/0	1.00	297/0	0.9909	70	0.9909	110
May	0.9952	207	0.9988	861	1.00	402/0	1.00	621/0	0.9936	155
June	1.00	609/0	1.00	633/0	1.00	479/0	0.9984	609	0.9984	609
Total	0.9984	640	0.9998	6036	0.9992	1333	0.9993	1493	0.9969	320

T/J = Total Transactions / Total Farecard Jams

C/C = Total Coins Inserted / Total Coin Jams

B/B = Total Bills Inserted / Total Bill Jams

T/O = Total Transactions / Total "Other" Failures

T/T = Total Transactions / Total Jams and "Other" Failures

R = Reliability

Mezzanine: Farragut West - 18th Street 1978-1979
Vendor: 32

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October	0.9936	156	0.9990	995	0.9961	258	0.9987	782	0.9885	87
December	0.9952	208	1.00	857/0	1.00	404/0	0.9952	208	0.9904	104
January	0.9922	128	0.9983	606	0.9952	207	1.00	511/0	0.9863	73
February	0.9988	808	0.9992	1328	0.9900	100	0.9963	269	0.9876	81
March					Out of Service					
April					Out of Service					
May	0.9980	495	1.00	668/0	0.9969	322	1.00	495/0	0.9960	248
June	1.00	538/0	0.9980	508	0.9978	445	1.00	538/0	0.9963	269
Total	0.9963	268	0.9992	1241	0.9958	236	0.9981	537	0.9904	104

T/J = Total Transactions / Total Farecard Jams

C/C = Total Coins Inserted / Total Coin Jams

B/B = Total Bills Inserted / Total Bill Jams

T/O = Total Transactions / Total "Other" Failures

T/T = Total Transactions / Total Jams and "Other" Failures

R = Reliability

Mezzanine: Farragut West - 18th Street 1978-1979
Vendor: 33

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October	0.9969	326	0.9978	458	0.9720	36	0.9939	163	0.9693	33
December	0.9943	174	0.9983	572	0.9850	67	0.9924	131	0.9732	37
January	1.00	381/0	0.9880	84	0.9968	311	0.9948	191	0.9790	48
February	Out of Service									
March	Data on DADS Tapes Illegible									
April	0.9979	478	0.9986	715	1.00	326/0	0.9979	478	0.9937	159
May	1.00	631/0	1.00	767/0	1.00	432/0	1.00	631/0	1.00	631/0
June	0.9913	115	1.00	413/0	1.00	283/0	1.00	460/0	0.9913	115
Total	0.9968	311	0.9976	418	0.9934	151	0.9968	311	0.9861	72

T/J = $\frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

C/C = $\frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

B/B = $\frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

T/O = $\frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

T/T = $\frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

R = Reliability

Mezzanine: Farragut West - 18th Street 1978-1979
Vendor: 34

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October	1.00	97/0	1.00	172/0	1.00	90/0	0.9897	97	0.9897	97
December	0.9973	365	1.00	964/0	0.9980	501	0.9986	729	0.9945	182
January	1.00	155/0	0.9978	451	0.9714	35	1.00	155/0	0.9871	78
February	0.9978	445	0.9979	474	0.9949	197	1.00	889/0	0.9921	127
March	Data on DADS Tapes Unreadable									
April	1.00	377/0	0.9978	450	0.9962	264	0.9947	189	0.9894	94
May	1.00	586/0	1.00	869/0	0.9883	86	0.9966	293	0.9898	98
June	1.00	412/0	1.00	1282/0	-	-	1.00	412/0	1.00	412/0
Total	0.9988	811	0.9993	1501	0.9945	182	0.9982	541	0.9926	135

T/J = $\frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

C/C = $\frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

B/B = $\frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

T/O = $\frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

T/T = $\frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

R = Reliability

Mezzanine: Farragut West - 18th Street 1978-1979
Vendor: 35

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October	0.9977	433	0.9981	533	0.9929	140	1.00	865/0	0.9908	108
December	0.9973	365	1.00	952/0	1.00	459/0	1.00	729/0	0.9973	365
January	0.9965	289	1.00	645/0	0.9907	108	1.00	578/0	0.9913	116
February	0.9983	576	0.9986	713	0.9951	203	0.9983	576	0.9913	115
March	Data on DADS Tapes Illegible									
April	1.00	560/0	0.9986	717	1.00	390/0	1.00	560/0	0.9982	560
May	0.9979	470	1.00	657/0	0.9967	304	0.9957	235	0.9915	118
June	1.00	656/0	1.00	739/0	1.00	382/0	1.00	656/0	1.00	656/0
Total	0.9982	554	0.9993	1372	0.9965	282	0.9993	1478	0.9944	177

T/J = Total Transactions / Total Farecard Jams

C/C = Total Coins Inserted / Total Coin Jams

B/B = Total Bills Inserted / Total Bill Jams

T/O = Total Transactions / Total "Other" Failures

T/T = Total Transactions / Total Jams and "Other" Failures

R = Reliability

Mezzanine: Rosslyn 1978-1979
Vendor: 30

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October					Out of Service					
December	0.9878	82	0.9989	944	0.9981	513	1.00	737/0	0.9851	67
January	0.9985	675	0.9953	215	0.9960	251	0.9985	675	0.9881	84
February	1.00	390/0	0.9981	519	0.9969	322	1.00	390/0	0.9949	195
March	0.9961	254	1.00	482/0	0.9968	311	1.00	508/0	0.9941	169
April	1.00	883/0	0.9980	497	0.9984	639	1.00	883/0	0.9966	294
May	1.00	700/0	1.00	831/0	0.9980	505	0.9986	700	0.9971	350
June	0.9989	903	1.00	903/0	0.9915	118	1.00	903/0	0.9922	129
Total	0.9973	369	0.9986	739	0.9963	269	0.9996	2398	0.9925	133

T/J = Total Transactions / Total Farecard Jams

C/C = Total Coins Inserted / Total Coin Jams

B/B = Total Bills Inserted / Total Bill Jams

T/O = Total Transactions / Total "Other" Failures

T/T = Total Transactions / Total Jams and "Other" Failures

R = Reliability

Mezzanine: Rosslyn 1978-1979
Vendor: 31

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October	0.9969	322	0.9967	308	0.9956	226	1.00	996/0	0.9896	97
December	0.9878	82	1.00	315/0	1.00	171/0	0.9796	49	0.9714	35
January	0.9989	902	1.00	1038/0	0.9917	120	1.00	902/0	0.9933	150
February	1.00	486/0	0.9984	627	0.9968	315	0.9979	486	0.9938	162
March	0.9989	944	1.00	1073/0	1.00	721/0	0.9958	236	0.9947	189
April	0.9976	421	0.992	1269	1.00	545/0	0.9988	841	0.9952	210
May	0.9986	732	0.9988	837	1.00	537/0	0.9986	732	0.9959	244
June	0.9988	846	0.9993	1505	0.9986	720	0.9988	846	0.9953	212
Total	0.9980	497	0.9990	987	0.9977	428	0.9978	459	0.9928	139

T/J = Total Transactions / Total Farecard Jams

C/C = Total Coins Inserted / Total Coin Jams

B/B = Total Bills Inserted / Total Bill Jams

T/O = Total Transactions / Total "Other" Failures

T/T = Total Transactions / Total Jams and "Other" Failures

R = Reliability

Mezzanine: Rosslyn 1978-1979
Vendor: 32

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October	0.9944	178	0.9993	1409	0.9978	452	0.9972	357	0.9888	89
December	0.9890	91	0.9990	997	0.9981	515	0.9973	365	0.9835	61
January	0.9990	990	0.9992	1195	0.9871	348	1.00	990/0	0.9960	248
February	0.9938	163	1.00	400/0	0.9895	95	1.00	325/0	0.9877	81
March	0.9931	146	1.00	148/0	0.9880	84	0.9945	182	0.9808	52
April	0.9990	980	1.00	1195/0	0.9956	226	0.9969	327	0.9929	140
May	0.9963	268	0.9993	1375	0.9938	162	1.00	1070/0	0.9925	134
June	0.9966	294	1.00	1387/0	1.00	706/0	0.9966	294	0.9932	147
Total	0.9956	229	0.9996	2269	0.9957	231	0.9994	458	0.9902	102

$T/J = \frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

$C/C = \frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

$B/B = \frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

$T/O = \frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

$T/T = \frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

R = Reliability

Mezzanine: Rosslyn 1978-1979
Vendor: 33

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October	0.9991	1144	1.00	1483/0	0.9960	251	0.9974	381	0.9939	163
December	0.9838	361	1.00	975/0	1.00	498/0	0.9945	181	0.9917	120
January	0.9920	125	0.9982	557	0.9978	460	1.00	751/0	0.9880	83
February	1.00	578/0	1.00	687/0	0.9949	197	0.9983	578	0.9948	193
March	0.9980	491	0.9982	564	0.9965	287	0.9980	491	0.9919	123
April	1.00	871/0	0.9978	459	0.9952	208	0.9989	871	0.9931	145
May	1.00	707/0	1.00	1101/0	0.9923	131	1.00	707/0	0.9958	236
June	1.00	847/0	0.9992	1291	0.9902	102	1.00	847/0	0.9941	169
Total	0.9983	600	0.9992	1237	0.9956	223	0.9983	600	0.9929	141

T/J = Total Transactions / Total Farecard Jams

C/C = Total Coins Inserted / Total Coin Jams

B/B = Total Bills Inserted / Total Bill Jams

T/O = Total Transactions / Total "Other" Failures

T/T = Total Transactions / Total Jams and "Other" Failures

R = Reliability

Mezzanine: Rosslyn 1978-1979
Vendor: 34

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October	0.9922	129	0.9969	328	1.00	328/0	1.00	514/0	0.9883	86
December	0.9916	119	0.9982	570	1.00	679/0	0.9916	119	0.9811	53
January	1.00	755/0	1.00	921/0	0.9980	493	0.9974	378	0.9960	252
February	0.9981	521	1.00	703/0	1.00	326/0	1.00	521/0	0.9981	521
March	1.00	1041/0	1.00	1308/0	0.9985	664	0.9990	1041	0.9981	521
April	1.00	904/0	1.00	1128/0	1.00	576/0	1.00	904/0	1.00	904/0
May	1.00	1149/0	0.9993	1397	1.00	789/0	0.9983	575	0.9974	383
June	0.9990	972	0.9992	1311	0.9975	401	0.9979	486	0.9938	162
Total	0.9979	486	0.9993	1427	0.9991	1164	0.9978	454	0.9943	175

T/J = $\frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

C/C = $\frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

B/B = $\frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

T/O = $\frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

T/T = $\frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

R = Reliability

Mezzanine: Rosslyn 1978-1979
Vendor: 38

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October	0.9983	579	1.00	598/0	0.9978	445	1.00	579/0	0.9965	290
December	0.9988	861	0.9980	505	0.9925	134	0.9988	861	0.9895	96
January	0.9953	213	0.9982	555	0.9799	50	1.00	213/0	0.9765	43
February	0.9942	174	0.9953	214	1.00	315/0	0.9971	347	0.9885	87
March	1.00	648/0	1.00	801/0	0.9934	152	1.00	648/0	0.9954	216
April	1.00	537	1.00	600/0	0.9974	389	0.9981	1537	0.9963	269
May	0.9990	1029	1.00	952/0	0.9974	387	1.00	1029/0	0.9971	343
June	0.9990	958	0.9991	1164	0.9987	791	1.00	958/0	0.9969	319
Total	0.9986	739	0.9992	1179	0.9960	249	0.9994	1724	0.9940	167

T/J = Total Transactions / Total Farecard Jams

C/C = Total Coins Inserted / Total Coin Jams

B/B = Total Bills Inserted / Total Bill Jams

T/O = Total Transactions / Total "Other" Failures

T/T = Total Transactions / Total Jams and "Other" Failures

R = Reliability

Mezzanine: Rosslyn 1978-1979
Vendor: 39

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October	0.9993	1411	0.9981	520/0	0.9890	91	1.00	1411/0	0.9950	202
December	0.8333	6	1.00	96/0	1.00	45/0	0.9833	60	0.7833	5
January	0.9597	25	1.00	118/0	1.00	87/0	0.9919	124	0.9516	21
February					Data Unavailable					
March	1.00	130/0	1.00	216/0	1.00	86/0	0.9923	130	0.9923	130
April	0.9977	434	1.00	507/0	0.9954	219	1.00	434/0	0.9954	217
May					Out of Service					
June					Out of Service					
Total	0.9912	114	0.9993	1457	0.9933	147	0.9986	720	0.9866	74

T/J = Total Transactions / Total Farecard Jams

C/C = Total Coins Inserted / Total Coin Jams

B/B = Total Bills Inserted / Total Bill Jams

T/O = Total Transactions / Total "Other" Failures

T/T = Total Transactions / Total Jams and "Other" Failures

R = Reliability

Mezzanine: Rosslyn 1978-1979
Vendor: 40

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October	0.9983	606	1.00	750/0	1.00	435/0	0.9983	606	0.9967	303
December	0.9924	133	1.00	483/0	1.00	298/0	0.9950	199	0.9874	80
January	1.00	647	0.9987	253	0.9979	470	1.00	647/0	0.9938	162
February					Out of Service					
March	0.9981	541	1.00	667/0	0.9974	385	0.9945	180	0.9908	108
April	0.9981	543	1.00	625/0	0.9975	408	1.00	543/0	0.9963	272
May	0.9973	368	1.00	672/0	0.9966	299	1.00	736/0	0.9946	184
June	0.9965	288	1.00	1041/0	0.9986	715	1.00	863/0	0.9954	216
Total	0.9975	394	0.9994	1665	0.9982	551	0.9986	722	0.9940	167

T/J = Total Transactions / Total Farecard Jams

C/C = Total Coins Inserted / Total Coin Jams

B/B = Total Bills Inserted / Total Bill Jams

T/O = Total Transactions / Total "Other" Failures

T/T = Total Transactions / Total Jams and "Other" Failures

R = Reliability

Mezzanine: Rosslyn 1978-1979
Vendor: 41

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October	0.9947	187	1.00	416/0	1.00	283/0	1.00	374/0	0.9947	187
December	0.9813	54	1.00	145/0	0.9880	84	0.9626	27	0.9346	15
January	0.9971	351	1.00	348/0	0.9934	153	1.00	351/0	0.9915	117
February	1.00	467/0	1.00	566/0	0.9941	170	1.00	467/0	0.9957	234
March	0.9701	36	1.00	411/0	0.9885	87	0.9970	335	0.9582	24
April	1.00	461/0	1.00	492/0	0.9874	80	1.00	461/0	0.9870	92
May	1.00	113/0	0.9972	182	No Transactions		0.9823	57	0.9646	28
June					Out of Service					
Total	0.9932	147	0.9993	1371	0.9922	128	0.9968	315	0.9832	60

T/J = Total Transactions / Total Farecard Jams

C/C = Total Coins Inserted / Total Coin Jams

B/B = Total Bills Inserted / Total Bill Jams

T/O = Total Transactions / Total "Other" Failures

T/T = Total Transactions / Total Jams and "Other" Failures

R = Reliability

Mezzanine: Rosslyn 1978-1979
Vendor: 42

	Ticket Transport		Coin Acceptor		Bill Validator		Other		Total	
Month	R	T/J	R	C/C	R	B/B	R	T/O	R	T/T
October	1.00	319/0	1.00	358/0	1.00	247/0	0.9969	319	0.9969	319
December	1.00	588/0	1.00	689/0	0.9956	229	1.00	588/0	0.9966	294
January	1.00	397/0	0.9886	88	0.9939	166	0.9950	199	0.9798	50
February	1.00	121/0	1.00	135/0	1.00	94/0	0.9917	121	0.9917	121
March	1.00	379/0	1.00	434/0	1.00	299/0	0.9974	379	0.9974	379
April	1.00	303/0	1.00	329/0	1.00	228/0	0.9967	303	0.9967	303
May	0.9968	319	1.00	564/0	0.9981	538	0.9984	638	0.9937	160
June	1.00	770/0	1.00	902/0	0.9983	323	0.9948	193	0.9922	128
Total	0.9994	1758	0.9989	941	0.9975	406	0.9969	320	0.9932	147

T/J = $\frac{\text{Total Transactions}}{\text{Total Farecard Jams}}$

C/C = $\frac{\text{Total Coins Inserted}}{\text{Total Coin Jams}}$

B/B = $\frac{\text{Total Bills Inserted}}{\text{Total Bill Jams}}$

T/O = $\frac{\text{Total Transactions}}{\text{Total "Other" Failures}}$

T/T = $\frac{\text{Total Transactions}}{\text{Total Jams and "Other" Failures}}$

R = Reliability

APPENDIX 5

95 PERCENT CONFIDENCE INTERVALS FOR AFC EQUIPMENT RELIABILITY AND AVAILABILITY MEASURES

TOTAL RELIABILITY

	1978 - 1979	Retrofit A	Retrofit B
Gates	0.9978 - 0.9982 (0.9980)	0.9984 - 0.9988 (0.9986)	0.9995 - 0.9997 (0.9996)
Vendors	0.9912 - 0.9922 (0.9917)	0.9913 - 0.9937 (0.9925)	0.9954 - 0.9970 (0.9962)
Add-Fares	0.9866 - 0.9926 (0.9896)	0.9849 - 0.9913 (0.9881)	0.9921 - 0.9965 (0.9943)

FARECARD RELIABILITY

Gates	0.9986 - 0.9990 (0.9980)	0.9992 - 0.9994 (0.9993)	0.9995 - 0.9995 (0.9999)
Vendors	0.9985 - 0.9989 (0.9987)	0.9976 - 0.9988 (0.9982)	0.9995 - 0.9999 (0.9997)
Add-Fares	0.9978 - 0.9986 (0.9982)	0.9911 - 0.9959 (0.9935)	0.9979 - 0.9999 (0.9989)

COIN RELIABILITY

Vendors	0.9986 - 0.9990 (0.9988)	0.9988 - 0.9994 (0.9991)	0.9986 - 0.9994 (0.9990)
Add-Fares	0.9990 - 1.0000 (0.9995)	0.9966 - 0.9994 (0.9980)	0.9981 - 0.9999 (0.9990)

BILL RELIABILITY

Vendors	0.9988 - 0.9992 (0.9990)	0.9970 - 0.9986 (0.9978)	0.9977 - 0.9989 (0.9983)
Add-Fares	0.9951 - 0.9855 (0.9753)	0.9958 - 1.0000 (0.9979)	0.9959 - 0.9997 (0.9978)

AVAILABILITY

	1978 - 1979	Retrofit A	Retrofit B
Gates	92.34 - 93.08 (92.71)	0.9527 - 0.9581 (0.9554)	0.9510 - 0.9576 (0.9543)
Vendors	83.90 - 84.26 (84.08)	0.9118 - 0.9204 (0.9161)	0.9735 - 0.9787 (0.9761)
Add-Fares	95.58 - 96.76 (96.17)	0.9265 - 0.9401 (0.9333)	0.9833 - 0.9901 (0.9867)

APPENDIX 6

REPORT OF NEW TECHNOLOGY

REPORT OF NEW TECHNOLOGY

The work performed under this contract has assisted the Washington Metropolitan Area Transit Authority in evaluating their automatic fare collection equipment and for the first time has led to the use of standardized measures of reliability and availability for evaluating automatic fare collection equipment. The use of these standardized measures will be applied to other rail rapid transit properties in an attempt to develop an industry wide data base on fare collection equipment performance.

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